









# NAVAL POSTGRADUATE SCHOOL

## Monterey, California



# THESIS

T7621

**NATURAL CONVECTION COOLING OF A 3 BY 3  
ARRAY OF RECTANGULAR PROTRUSIONS IN AN  
ENCLOSURE FILLED WITH DIELECTRIC LIQUID:  
EFFECTS OF BOUNDARY CONDITIONS  
AND COMPONENT ORIENTATION**

by

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December 1988

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T242393



Unclassified

Security Classification of this page

## REPORT DOCUMENTATION PAGE

1a Report Security Classification <b>Unclassified</b>				1b Restrictive Markings			
2a Security Classification Authority				3 Distribution Availability of Report			
2b Declassification/Downgrading Schedule				Approved for public release; distribution is unlimited.			
4 Performing Organization Report Number(s)				5 Monitoring Organization Report Number(s)			
6a Name of Performing Organization Naval Postgraduate School		6b Office Symbol (If Applicable)		7a Name of Monitoring Organization Naval Postgraduate School			
6c Address (city, state, and ZIP code) Monterey, CA 93943-5000				7b Address (city, state, and ZIP code) Monterey, CA 93943-5000			
8a Name of Funding/Sponsoring Organization		8b Office Symbol (If Applicable)		9 Procurement Instrument Identification Number			
8c Address (city, state, and ZIP code)				10 Source of Funding Numbers			
				Program Element Number		Project No	Task No
						Work Unit Accession No	
11 Title (Include Security Classification) <b>Natural Convection Cooling of a 3 by 3 Array of Rectangular Protrusions in an Enclosure Filled with Dielectric Liquid: Effects of Boundary Conditions and Component Orientation</b>							
12 Personal Author(s) <b>Edgardo I. Torres</b>							
13a Type of Report Master's Thesis		13b Time Covered From To		14 Date of Report (year, month, day) December 1988		15 Page Count 139	
16 Supplementary Notation The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.							
17 Cosati Codes			18 Subject Terms (continue on reverse if necessary and identify by block number)				
Field	Group	Subgroup	Direct Immersion, Natural Convection Cooling, Dielectric Liquid Protrusions, Enclosure, Simulated Circuit Board, Strip Heaters, Flow Visualization, Convective Heat Transfer				
19 Abstract (continue on reverse if necessary and identify by block number) An experimental investigation of natural convection immersion cooling of two configurations of discrete heat sources in an enclosure filled with Fluorinert FC-75 has been conducted. A three by three array of rectangular protrusions was employed. In the first study, using the same equipment set-up of Benedict [Ref. 13], the influence of changing the enclosure bottom surface boundary condition on flow patterns and heat transfer characteristics was examined. Both insulated and uniform temperature boundary conditions were considered. In the second set of experiments, a new chamber with the protrusions oriented vertically was assembled and effects of component orientation on the heat transfer characteristics were examined. In addition, timewise variations of temperature in several locations were measured and interpreted at different power levels.							
20 Distribution/Availability of Abstract <input checked="" type="checkbox"/> unclassified/unlimited <input type="checkbox"/> same as report <input type="checkbox"/> DTIC users				21 Abstract Security Classification <b>Unclassified</b>			
22a Name of Responsible Individual Professor Yogendra Joshi				22b Telephone (Include Area code) (408) 646-3400		22c Office Symbol 69ji	

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted

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Protrusions in an Enclosure Filled with Dielectric Liquid: Effects  
of Boundary Conditions and Component Orientation**

by

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Submitted in partial fulfillment of the  
requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

from the

NAVAL POSTGRADUATE SCHOOL  
December 1988



## **ABSTRACT**

An experimental investigation of natural convection immersion cooling of two configurations of discrete heat sources in an enclosure filled with Fluorinert FC-75 has been conducted. A three by three array of rectangular protrusions was employed.

In the first study, using the same equipment set-up of Benedict [Ref. 13], the influence of changing the enclosure bottom surface boundary condition on flow patterns and heat transfer characteristics was examined. Both insulated and uniform temperature boundary conditions were considered.

In the second set of experiments, a new chamber with the protrusions oriented vertically was assembled and effects of component orientation on the heat transfer characteristics were examined. In addition, timewise variations of temperature in several locations were measured and interpreted at different power levels.

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## TABLE OF SYMBOLS AND ABBREVIATIONS

Symbol	Description	Units
A	Area	m <sup>2</sup>
$\alpha$	Thermal diffusivity	m <sup>2</sup> /sec
$\beta$	Volumetric expansion coefficient	1/K
c <sub>p</sub>	Specific heat	J/kg-°C
emf	Thermocouple voltage	volt
g	Acceleration of gravity	m/sec <sup>2</sup>
Gr	Grashof number	Dimensionless
h	Heat transfer coefficient	W/m <sup>2</sup> -°C
k	Thermal conductivity	W/m-°C
L	Characteristic length	m
L1	Component length in the vertical direction	m
L2	Summation of the ratios of the component fluid exposed areas to their perimeters	m
Nu	Nusselt number	Dimensionless
Nu1	Nusselt number with length scale L1	Dimensionless
Nu2	Nusselt number with length scale L2	Dimensionless
$\nu$	Kinematic viscosity	m <sup>2</sup> /sec
$\omega$	Uncertainty in the variables	Various

Power	Power dissipated by the heaters	W
$Pr$	Prandtl number	Dimensionless
$Q_{conv}$	Energy added to the fluid	W
$Q_{in}$	Energy input to the heaters	W
$Q_{loss}$	Energy loss by conduction	W
$Q_{net}$	Net power dissipated by the heater	W
$R_c$	Total thermal resistance	$^{\circ}\text{C}/\text{W}$
$R_p$	Resistance of the precision resistor	ohms
$Ra_f$	Flux-based Rayleigh number	Dimensionless
$Ra_t$	Temperature-based Rayleigh number	Dimensionless
$D$	Density	$\text{kg}/\text{m}^3$
$T_{avg}$	Average of component temperature	$^{\circ}\text{C}$
$T_b$	Back surface temperature of board	$^{\circ}\text{C}$
$T_c$	Average heat exchanger temperature	$^{\circ}\text{C}$
$T_f$	Average film temperature	$^{\circ}\text{C}$
$T_s$	Back surface temperature of the component	$^{\circ}\text{C}$
$T_{sink}$	Average temperature of the heat exchangers	$^{\circ}\text{C}$
$V_h$	Voltage Across the Heaters	Volts
$V_{in}$	Input voltage	Volts
$w$	Chamber width	m
$W$	Unit of power	W





## **I. INTRODUCTION**

### **A. STATEMENT OF THE PROBLEM**

With the increase in circuit packaging density associated with the miniaturization of microelectronic components, heat dissipation has become a major problem in the design and construction of digital computers and high-power electronic equipment in general. Several alternatives to the solution of the problem have been studied in the past 10 years, including that of Chu [Ref. 1]. Among these, immersion cooling appears to be one of the most effective for achieving high heat-transfer coefficients.

### **B. IMMERSION COOLING: ANALYTICAL AND EXPERIMENTAL STUDIES**

From the construction of the first electronic digital computer, the solution to the problem of heat dissipation from high packaging density electronic equipment has not been easy. Even though very interesting forced convection methods have been studied and very frequently used (Chu [Ref. 1] describes several methods of air- and water-forced convection cooling), the hardware that has to be added to supply the additional power and to store and circulate the cooling liquid can be cumbersome in any application.

The direct immersion of the electronic circuitry into dielectric liquids improves its cooling capability significantly. Baker [Ref. 2] found liquid cooling by free convection to be more than three times as

effective as free convective air cooling of the same device. He made heat transfer measurements from thin-film tantalum nitride resistors evaporated on Corning 7059 glass substrates. The substrates were 1.0 by 2.6 by 0.12 cm. All resistors were rectangular, with their height (dimension parallel to the flow) one-half their base. The surface areas of the resistors were 0.0106, 0.104, 0.477, and 2.00 cm<sup>2</sup>. Two liquids were used in the study: freon with a Prandtl number of 3.9, and Dow Corning #200 silicone dielectric liquid with a Prandtl number of 126. The results showed that the heat transfer coefficient is approximately proportional to the cube root of the reciprocal of viscosity. It was also found that the convection coefficient does increase significantly as the source size decreases. The free convection heat transfer coefficient for the smallest source was more than an order of magnitude greater than for the largest source operated under the same conditions.

In a following study, Baker [Ref. 3] also examined different cooling techniques, such as nucleate boiling, forced convection, and bubble-induced mixing for cooling small heat sources.

Park and Bergles [Ref. 4] conducted experimental studies of natural convection from discrete flush-mounted rectangular heat sources on a circuit board substrate. Micro-electronic circuit elements were simulated with thin foil heaters supplied with DC power. Measurements were also made for protruding heaters of varying widths, in water and R-113. They found and documented the increase in heat transfer coefficient with decreasing width. This effect was greater in R-113 than in water. Also, for protruding heaters, the heat transfer

coefficients for the upper heaters in an array were found to be higher than those for the lower heaters. This behavior was not observed for flush-mounted heaters. As the distance between heaters increased, so did the heat transfer coefficients.

Chen, et al. [Ref. 5] made an experimental study of natural convection heat transfer in a liquid-filled rectangular enclosure with 10 protruding heaters from one vertical wall. The top surface of the enclosure maintained at a uniform temperature acted as the heat sink. All other surfaces, except the heater locations, were unheated. The enclosure was 16.7 cm in height, 2.3 cm in width, and 19.6 cm in depth (horizontal z-direction of the heaters). The 10 heaters were 0.8 cm high, 1.11 cm wide, and 19.6 cm deep. The vertical spacing between heaters was equal to the heater height. Distilled water and ethylene glycol were used as working fluids. Experimental results show that the bottom heater (heater 1), except for high Rayleigh number runs, has the highest heat transfer coefficient. The heat transfer coefficients at heaters 7, 8, and 9 are nearly the same and present the lowest values among the heaters. It was also shown that heat transfer coefficient decreases up to heater 7. At high Rayleigh numbers, the top heater (10) has the highest heat transfer coefficients. The flow visualization carried out indicates a core flow within the enclosure and a recirculating cell in the gap between heaters. Approximate measurements of the fluid velocity were provided from the particle traces in the flow visualization.

Keyhani, et al. [Ref. 6] experimentally studied the buoyancy-driven flow and heat transfer in a vertical cavity with discrete flush heat sources on one vertical wall while the other vertical wall was cooled at a constant temperature. This enclosure contained 11 alternatively unheated and flush-mounted rows of isoflux heated strips. The liquid was ethylene-glycol with a Prandtl number of 150.

To examine the flow structure, visualization experiments were conducted for several power inputs. Finely ground aluminum powder (5 to 20 microns in size) was used to visualize the flow. The observed flow for a power input of 10 watts was highly structured except for small regions near the end walls. A primary flow circulating from the hot wall to the cold wall, a secondary flow with the same sense of circulation as the primary flow, and a tertiary flow in the opposite direction of the secondary flow were observed in the photographs taken at this power level. At a higher power level of 40 watts, the flow pattern above the mid-height region of the cavity showed transition from laminar to turbulent flow along the surface with heaters. The downward flow along the cold wall was still laminar. For a fixed power input, the heat transfer coefficient generally decreased with increase in height (or heater number). The rate at which Nusselt number decreased with the increase in heater number was found to be a strong function of the heater location.

Kelleher, et al. [Ref. 7] and Lee, et al. [Ref. 8] studied experimentally and numerically the cooling by natural convection of a water-filled rectangular enclosure with a long heater protruding from one vertical

wall and conducted flow visualization and heat transfer measurements with the heater at three different elevations. They found the two-dimensional flow to be dual-celled, consisting of a buoyancy-driven upper cell, in which the major part of the fluid motion takes place and which accounts for the majority of the convective heat transfer, and a shear-driven lower cell in which the fluid motion arises due to the viscous drag from the upper cell.

Liu, et al. [Ref. 9] used a three-dimensional finite difference method to study the natural convection cooling of an array of chips mounted on a vertical wall of a three-dimensional rectangular enclosure filled with a dielectric fluid Fluorinert FC 75. They found the long time solution to be oscillatory. Maximum chip temperatures were found on the top surfaces of the three top chips. However, these maximum temperatures did not all occur at the same time, but alternated among these three chips as time proceeded in a rather regular fashion. It was also observed that the bottom sink was quite ineffective in removing heat from the enclosure and that the convective circulation was essentially limited to the chip areas.

Joshi, et al. [Ref. 10] carried out an experimental investigation to study the natural convection cooling of a 3 by 3 array of heated protrusions in a rectangular enclosure filled with dielectric fluid FC-75. They observed that at low power levels (0.1 watts), the flow structure was largely determined by the thermal conditions at the enclosure surfaces. With increasing power levels (0.7 to 3.0 watts), an upward flow developed adjacent to each column of components. The flow away

from the elements became strongly three-dimensional and time-dependent with increasing thermal inputs. Component surface temperatures were used to obtain a heat transfer correlation over the range of power levels examined.

Liu, et al. [Ref. 11] carried out a three-dimensional numerical study of immersion cooling of a chip array by laminar natural convection in a rectangular enclosure filled with a dielectric liquid. They determined the local temperature responses on the chip surfaces, their dynamic behaviors, and their dependence on the enclosure gap size. It was found that the temperature responses are decidedly oscillatory with wave forms ranging from simple to complex, and that maximum chip surface temperatures occur on the top row of chips for large gap sizes but oscillate among all three rows of chips for small gap sizes.

### **C. OBJECTIVES**

The work reported here is a continuation of thesis research conducted at the Naval Postgraduate School by Pamuk [Ref. 12] and Benedict [Ref. 13]. The numerical studies by Liu, et al. [Ref. 9] and Liu, et al. [Ref. 11] were the motivation for some of the specific investigations carried out.

The objectives of the present investigation are twofold: The first is to examine the effect of bottom surface boundary condition on thermal transport in the natural convection cooling of a 3 by 3 array of horizontally arranged protruding elements on a vertical wall. The second objective is to examine heat transfer, fluid flow characteristics,

and the influence of the width of the chamber during the natural convection cooling of a 3 by 3 array of vertically arranged protruding elements on a vertical wall. Temperature fluctuation measurements were plotted and compared with existing numerical analysis of Liu, et al. [Refs. 9 and 11] and Benedict [Ref. 13]. For both studies, flow visualizations were also carried out.

## II. EXPERIMENTAL SET-UP

### A. GENERAL CONSIDERATIONS

Two different experimental configurations were used for the studies reported here. In the first, a 3 by 3 array of rectangular elements with the largest dimension aligned horizontally was examined. In the second study, the largest dimensions were in the vertical direction. The two experimental configurations are next described.

The details of the experimental procedures are available in Benedict [Ref. 13]. The Data Acquisition Programs were the same as used by Pamuk [Ref. 12] and Benedict [Ref. 13] with minor modifications in output format and number of channels. These programs are collected in Appendix D.

#### 1. Experimental Set-Up for the Horizontal Arrangement

A schematic sketch of the arrangement is provided in Figure 2.1 (after Benedict [Ref. 13]). The configuration is the same as the one used by Joshi, et al. [Ref. 9] and Benedict [Ref. 13]. The distribution of the components and the top view of the chamber are illustrated in Figures 2.2 and 2.3 (both after Benedict [Ref. 13]).

This part of the thesis examines the effect of changing the enclosure bottom surface boundary condition on the overall thermal behavior of the system. A more detailed description of the experimental arrangement can be found in Benedict [Ref. 13].



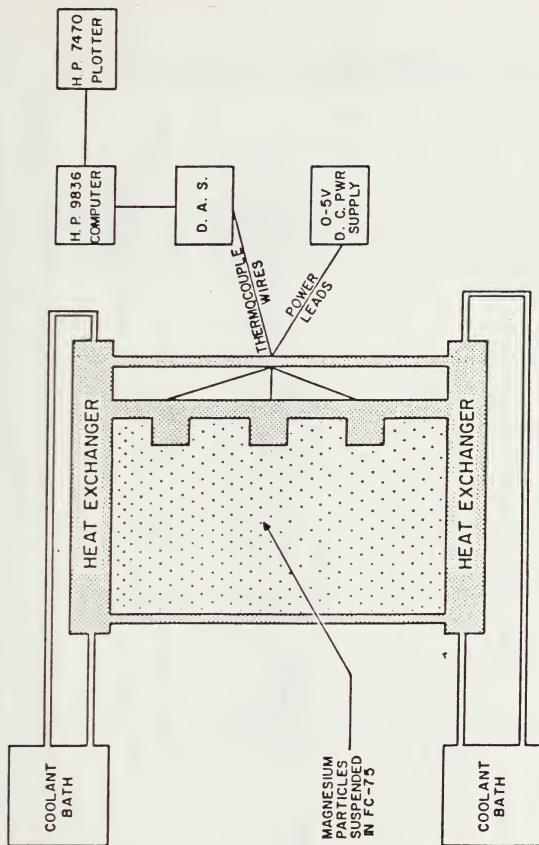


Figure 2.1 Schematic of Entire Assembly

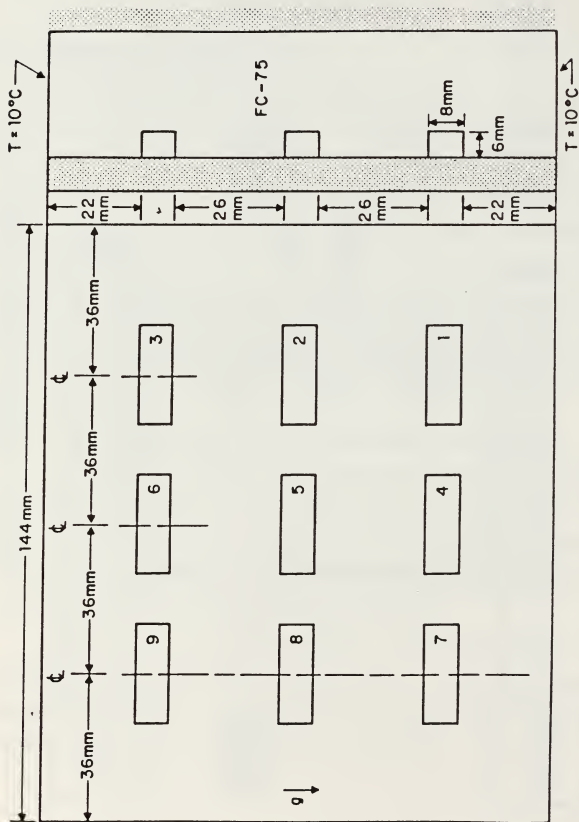


Figure 2.2 Simulated Circuit Card for the Horizontal Arrangement

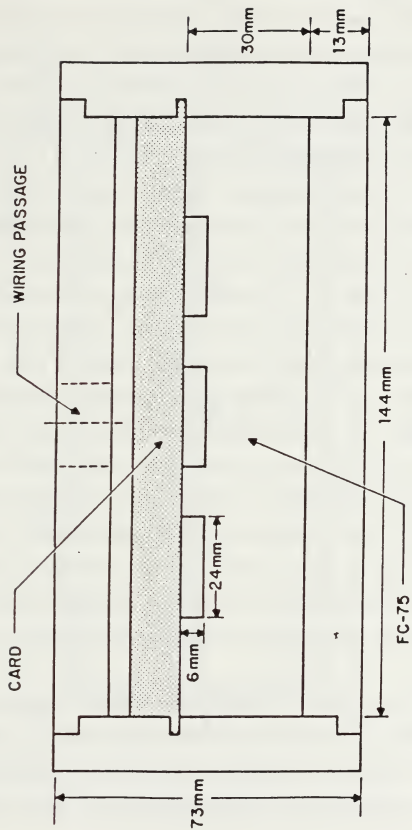


Figure 2.3 Top View of Horizontally Arranged Components Chamber

## **2. Experimental Set-Up for the Vertical Arrangement**

The chamber assembly, illustrated in Figure 2.4 was made of 19.05 mm plexiglass with dimensions of 241.13 mm length, 152.0 mm height, and 120.65 mm width. As in the first arrangement, the chamber was filled with FC-75, a dielectric fluid through tubing at the bottom of the chamber.

In both experimental configurations, two heat exchangers, one at the top and one at the bottom, were used (see Figure 2.1). The design of the exchangers for the first configuration is described in Joshi, et al. [Ref. 10]. In the second study, several modifications were made to reduce the heat transfer from the outside environment to the colder circulating water. The resulting design is seen in Figure 2.5. The external walls of both top and bottom heat exchangers were made of plexiglass. The walls acting as the top and bottom of the fluid-filled enclosure were aluminum plates 3 mm thick, chosen to provide an almost isothermal surface condition. Inlet and outlet headers were provided for flow distribution. Three thermocouples, symmetrically placed along the plate length, were used for the calculation of the average surface temperatures. The heat exchangers could be accessed easily to block one or more of the channels to reduce the coolant flow rates.

A 3 by 3 array of discrete protrusions, vertically arranged (see Figure 2.6), was mounted on a 19.05 mm thick plexiglass card. The card was slid into the chamber and was kept in location by plexiglass supports that prevented its linear movement as well as rotation.

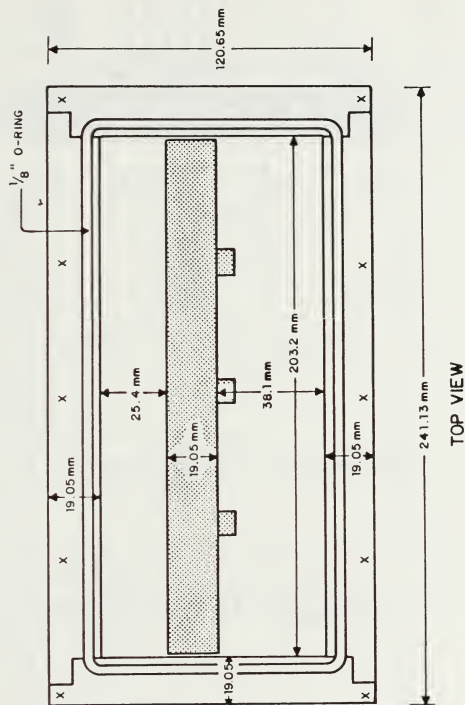


Figure 2.4 Chamber Assembly for the Vertical Arrangement

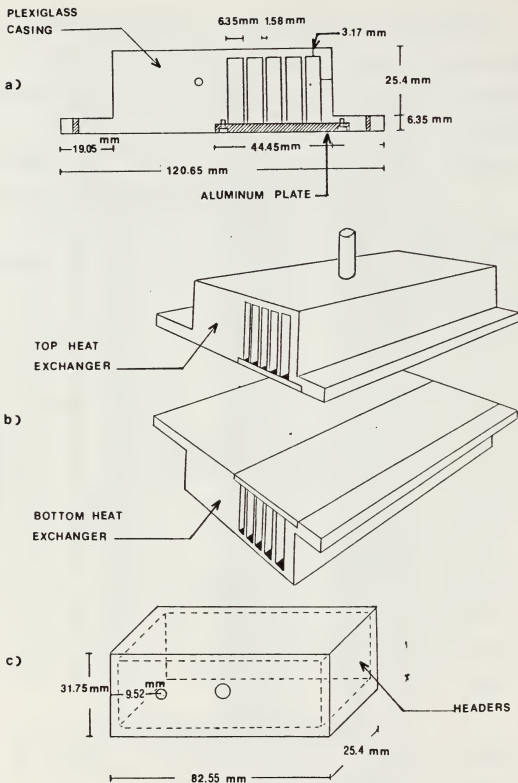


Figure 2.5 Heat Exchangers

(a) Cross-Sectional View; (b) Isometric View;  
(c) Inlet and Outlet Headers

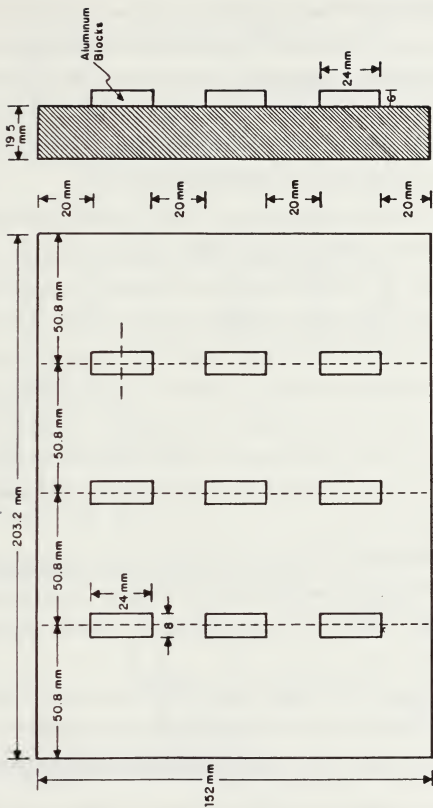


Figure 2.6 Simulated Circuit Card for the Vertical Arrangement

The chamber design allowed the replacement of the card in a simple way. The upper heat exchanger could be removed and the new card could be easily installed. This permits the installation of different card configurations (staggered, flush mounted, etc.) in the future without much additional effort. By moving the card back or forth, the chamber width could be changed. This was done in order to study the effect of this parameter in the overall heat transfer.

The heated components in both studies were aluminum blocks of 8 mm by 24 mm and 6 mm high (see Figure 2.7—after Benedict [Ref. 13]). The dimensions and geometry simulate approximately a 20-pin dual-in-line-package. A nearly uniform heat flux condition was maintained at the base of each block by attaching a foil-type heater with a resistance of about 11 ohms. The foil heaters contained a network of Iconel foil mounted on a Kapton backing and were 23.6 mm by 7.6 mm in dimension and were bonded to the base of each aluminum block using a high thermal conductivity epoxy (Omega Bond 101).

Temperatures at the center of each fluid exposed component face were determined using .127 mm diameter copper-constantan thermocouples. Thermocouple locations on each heater are illustrated in Figure 2.7.

All the thermocouples were connected to an HP-3497 automatic data acquisition system controlled by an HP-9826 microcomputer. Power to the heaters was supplied by a 0-40 volt, 0-1A DC



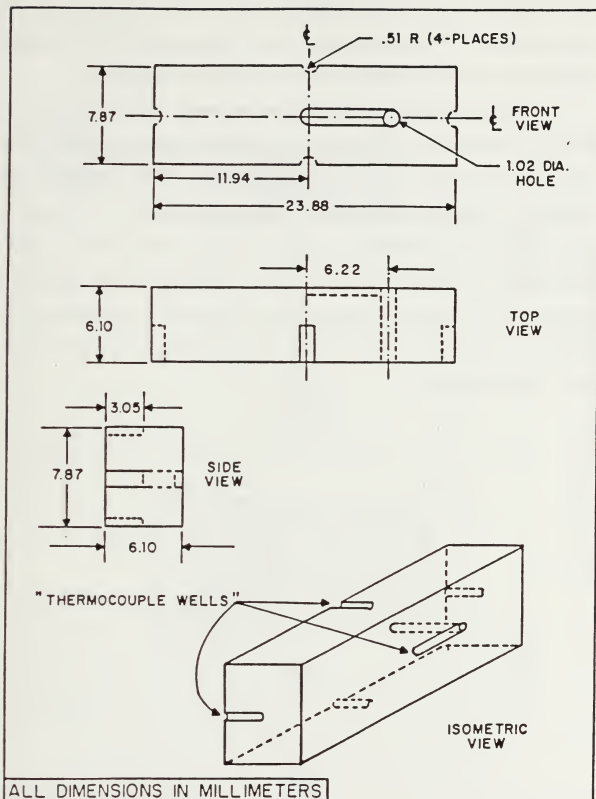


Figure 2.7 Heating Element and Thermocouple Location

power supply. A simultaneous measurement of the overall voltage drop, along with the voltage drop across each heater, allowed the computation of the power dissipation through individual heaters.

Flow visualization was carried out with a 4 mw Helium-Neon laser for illumination. To produce a plane of light, a cylindrical lens was used (see Figure 2.8—after Benedict [Ref. 13]). The laser sheet illuminated magnesium particles (specific gravity of 1.74) that were added to the FC-75 (specific gravity of 1.76 at 25° C). This technique allowed for the visualization of a single two-dimensional plane of the flow field. Time exposure photographs of the flow were obtained using a Nikon F-3 camera with a 50 mm lens, a MD-4 motor drive, and a MT-2 intervalometer.

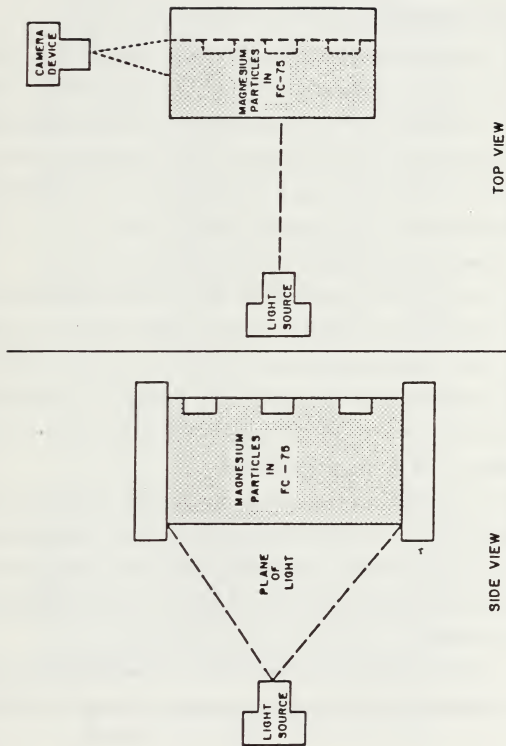


Figure 2.8 Flow Visualization Set-Up

### **III. RESULTS AND DISCUSSIONS FOR HORIZONTAL ARRANGEMENT**

#### **A. FLOW PATTERNS**

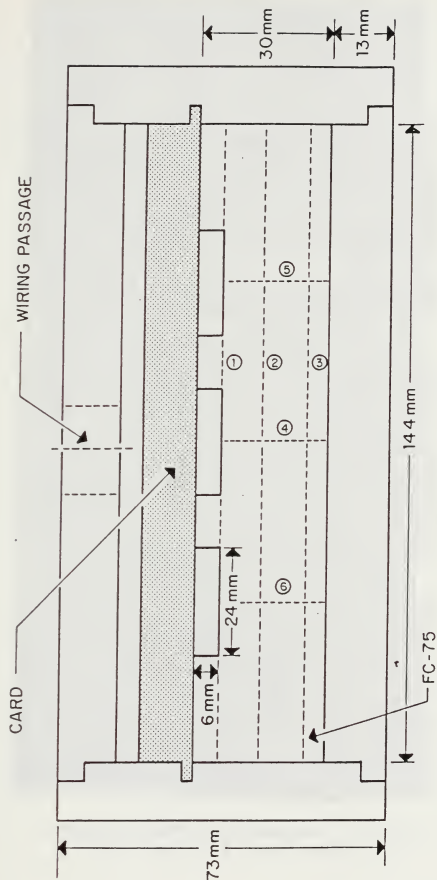
Flow visualization was carried out in six vertical planes, seen in Figure 3.1 (after Benedict [Ref. 13], for the two different bottom boundary conditions: 20° C and insulated. The three-dimensional transport responses, across the range of power dissipation of 0.1 W to 3.0 W, were inferred from these visualizations. In the following, a detailed description of the observed flows is provided.

##### **1. Flow Patterns for the Bottom Boundary at 20° C**

The flow patterns observed at several power dissipation levels from no dissipation to 3.0 W are collected in Figures 3.2 to 3.7. Visualization with no power (see Figures 3.2 and 3.3) was to examine the natural convection flow due only to the difference in temperature between the two heat exchangers, and its possible influence on the flow patterns, with the heaters turned on.

At no power, the flow consisted of a single clockwise cell that occupied the entire chamber. This overall flow was established as a result of the temperature differences between the enclosure walls. The three-dimensionality of the flow was evident from visualizations in the various planes.

At 0.1 W, the pattern observed at no power in Figures 3.2 and 3.3 was completely distorted and no remains of the strong clockwise



The six vertical flow visualization planes are identified in the sketch.

**Figure 3.1 Top View of the Enclosure With the Card Placed in Position**

a



b



c



Figure 3.2 Visualization With No Power  
in Planes 1 (a), 2 (b), and 3 (c)

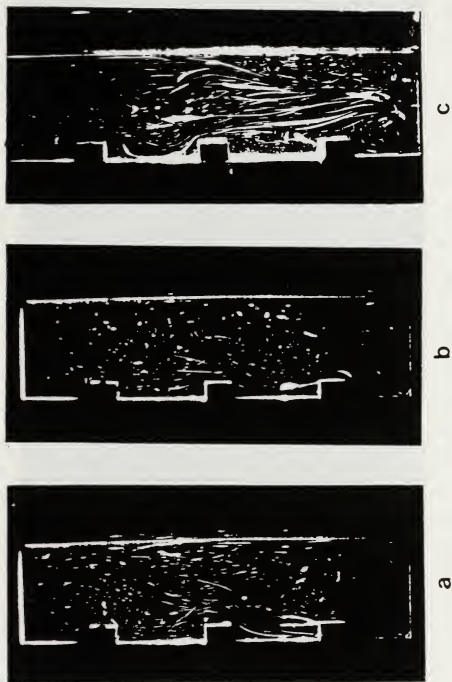


Figure 3.3 Visualization With No Power in Planes 4 (a), 5 (b), and 6 (c)

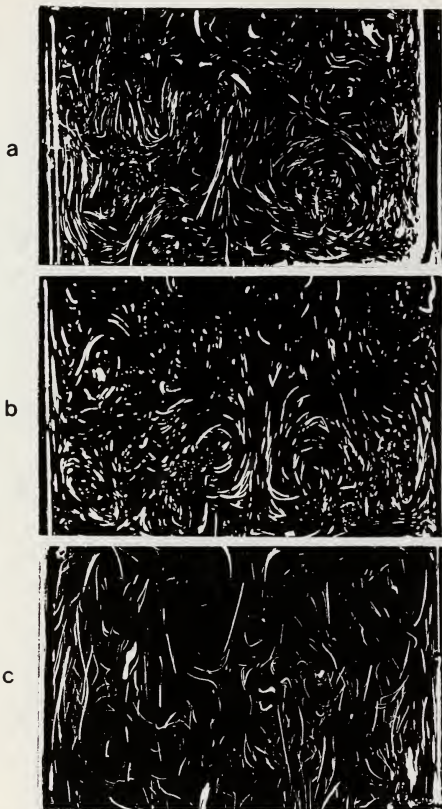


Figure 3.4 Visualization with 1.1 W  
in Planes 1 (a), 2 (b), and 3 (c)



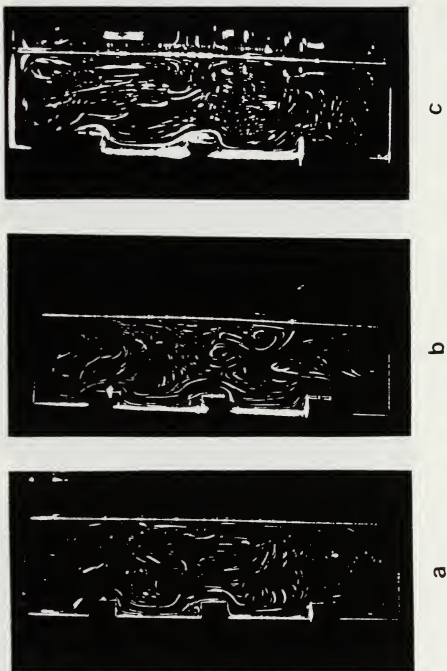


Figure 3.5 Visualization With 1.1 W in Planes 4 (a), 5 (b), and 6 (c)

a



b



c

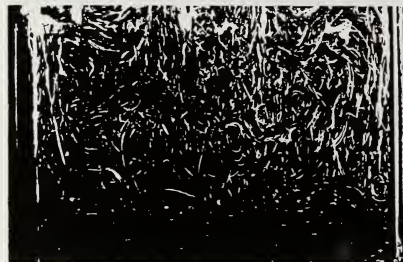


Figure 3.6 Visualization with 3.0 W  
in Planes 1 (a), 2 (b), and 3 (c)

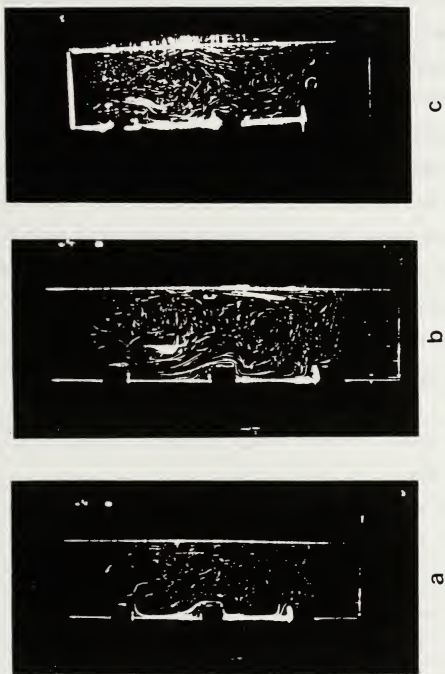


Figure 3.7 Visualization With 3.0 W in Planes 4 (a), 5 (b), and 6 (c)

flow were seen. Joshi, et al. [Ref. 10] at the same power level reported two very well defined large clockwise cells, one on each side of the central component column. The present visualization showed that the flow now was completely dominated by the relatively high temperature of the bottom heat exchanger. The effects of the buoyancy forces due to the power dissipation were small except in plane 1 (close to the heaters), where there was a well defined upflow.

In plane 2, the particle traces showed a decrease in velocity. Also, dark regions, as observed in Joshi, et al. [Ref. 10], were seen. These were, however, thinner and not well defined. These nearly quiescent regions appear due to the stable stratification produced by the bottom heat exchanger. Descending fluid from the top is unable to penetrate the colder layer of fluid at the bottom. In plane 3, a downflow resulted due to an increase in the density of the colder fluid, in contact with the upper heat exchanger, at 10° C.

At 1.1 W (see Figure 3.4), a well defined pattern could be observed in planes 1 and 2. Along the central column of heaters, the upflow was wider and stronger than near the adjacent columns. This flow was the result of the interaction of an upflow along the central column, a clockwise flow around the right column (heaters 1, 2, and 3), and a counterclockwise flow around the left column (heaters 7, 8, and 9). In plane 3, a downflow of cold liquid was seen. In Figure 3.5, flow patterns at 1.1 W in planes 4, 5, and 6 are illustrated. It is possible in these pictures to appreciate in a side view the strong upflow adjacent to the components. The basic difference with the flow

pattern found in the study by Joshi, et al. [Ref. 10] at the same power level is still that the inactive zone in the bottom of the chamber is not well defined.

With further increase in the power level, the flow in plane 1 exhibited stronger upflow near the components. The buoyancy forces generated by the power dissipation here were strong enough to extend their influence to planes 2 and 3. At 3.0 W, a very thin, dark layer was still observed at the bottom of the chamber (see Figure 3.6). A view of the flow patterns in planes 4, 5, and 6 is illustrated in Figure 3.7. This figure shows a buoyant fluid layer adjacent to the components. In the remaining chamber, the motion was completely random.

## **2. Flow Pattern With the Bottom Boundary Insulated**

The flow pattern for this condition showed similar trends as discussed in section A.1. The induced flow due to the difference in temperature between the two heat exchangers was not appreciable.

## **B. HEAT TRANSFER MEASUREMENTS**

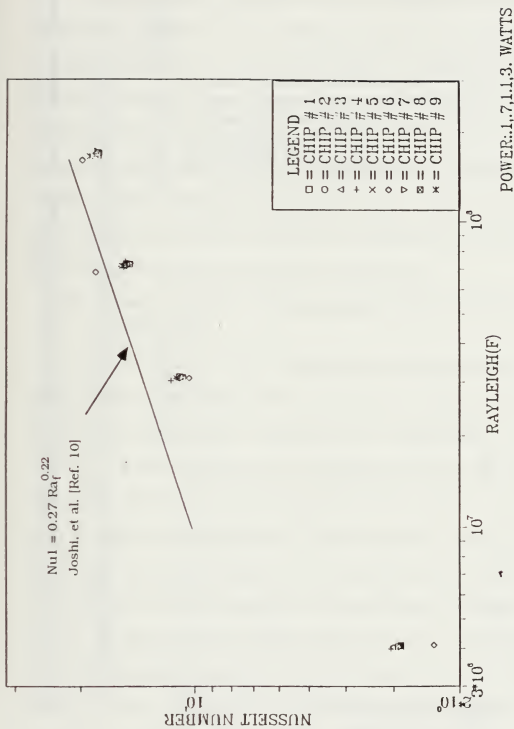
Heat transfer measurements were made at power levels of 0.1, 0.7, 1.1, 1.5, and 3.0 watts for the two bottom surface boundary conditions. The temperature at the top heat exchanger was maintained constant at 10° C in all experiments. Temperature and flux-based Rayleigh numbers ( $Ra_t$  and  $Ra_f$ ) were calculated in a manner identical to that discussed in Joshi, et al. [Ref. 10] and plotted versus Nusselt number ( $Nu_l$ ). These are defined in the Table of Symbols and Abbreviations.

## **1. Heat Transfer Measurements With the Bottom Boundary at 20° C**

Component surface temperature measurements at various power levels are collected in Tables 1 through 8 in Appendix C. The nondimensional heat transfer parameters in the form of Nusselt versus Rayleigh numbers are illustrated in Figures 3.8 and 3.9. In the same plots, the correlations found by Joshi, et al. [Ref. 10] were also plotted.

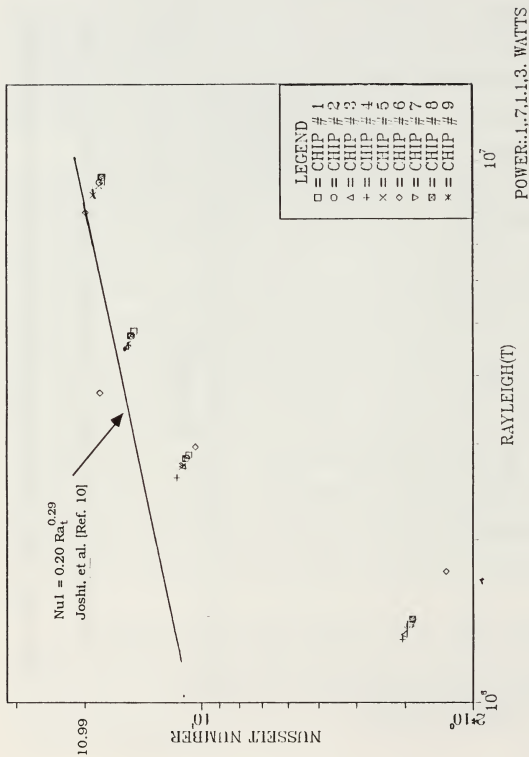
We can see that having the bottom heat exchanger at 20° C results in general in lower Nusselt numbers than those found by Joshi, et al. [Ref. 10] in the range of Rayleigh numbers considered. At higher power levels, when the temperature of the heaters was considerably higher than the bulk temperature of the dielectric fluid, the difference in Nusselt numbers is smaller than at lower power levels. The Nusselt number at a flux-based Rayleigh number of  $10^6$  found by Joshi, et al. [Ref. 10] was 20.4, while the Nusselt number obtained here for the same Rayleigh number was 19. At lower power levels 0.1 W and 0.7 W, the differences in Nusselt number were greater, and the decrease in the heat transfer coefficient was significant. The Nusselt number found by Joshi, et al. [Ref. 10] was 10.5 at a flux-based Rayleigh number of  $10^6$ , while the Nusselt obtained with the present configuration was 2.9.

At power levels of 0.1 W and 0.7 W, a small increase in the upper heaters' temperatures over the lower ones was observed. At higher power levels, the highest temperatures were found irregularly in different components.



Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

**Figure 3.8 Plot of Flux-Based Rayleigh Number Versus Nusselt Number**



Correlation found by Joshi, et al. [Ref.10] is plotted with a continuous line.

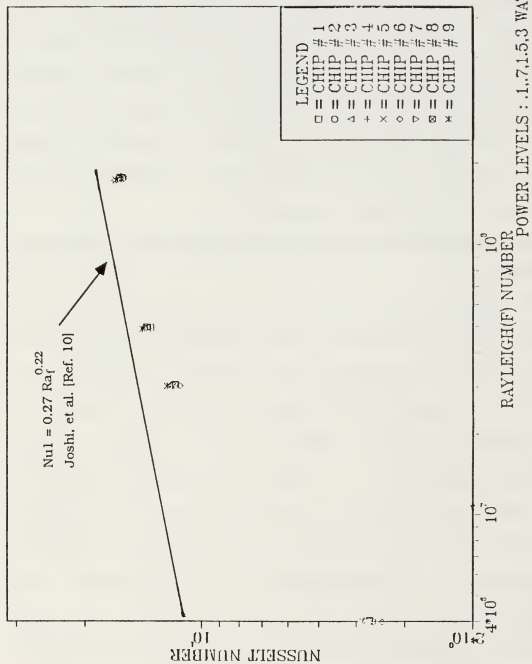
Figure 3.9 Plot of Temperature-Based Rayleigh Number Versus Nusselt Number



The component that presented the largest variations from the mean in the heat transfer coefficients was the upper component in the central column (heater 6). This is evidenced as deviations from the general trend of the obtained data. The variations (lower heat transfer coefficient at low power levels, and higher heat transfer coefficients at higher power levels) are expected because this component receives the influence of the combined upflowing streams (produced by the other heaters), as was observed and documented in the flow visualization results in Section A.1. The effect is greater at higher power levels when the component's temperature is substantially larger than the bottom heat exchanger temperature.

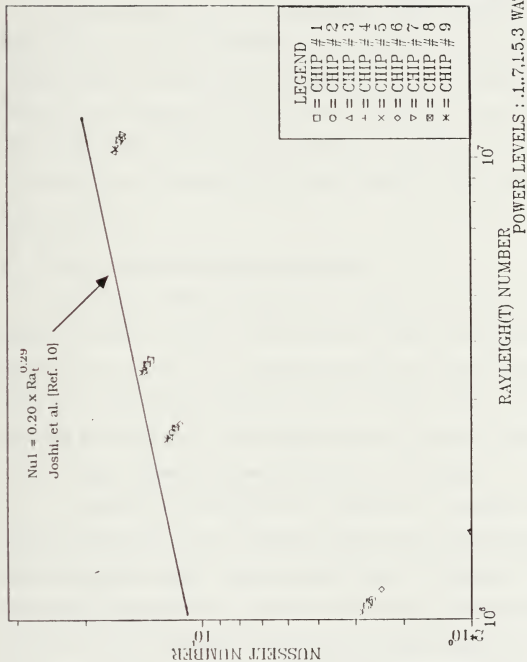
## **2. Heat Transfer Measurements With the Bottom Boundary Insulated**

The results of the temperature measurements with the bottom boundary insulated and the reduced dimensionless parameters are collected in Tables 9 through 16 in Appendix C. In Figures 3.10 and 3.11, flux and temperature Rayleigh numbers versus Nusselt numbers were plotted. Correlations found by Joshi, et al. [Ref. 10] were also plotted for comparison. It was seen that having the bottom heat exchanger insulated improved the cooling at low power levels (0.1 W and 0.7 W) over that obtained with the bottom boundary maintained at 20° C. This result is expected because now the temperature of the bottom boundary was 15° C at 0.1 W and 17° C at 0.7 W. At a power level of 3.0 W, no cooling improvement was observed. The temperature for the bottom boundary at 3.0 W was 22° C.



Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

Figure 3.10 Plot of Flux-Based Rayleigh Number Versus Nusselt Number



Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

Figure 3.11 Plot of Temperature-Based Rayleigh Number Versus Nusselt Number

Comparisons with the correlation obtained by Joshi, et al. [Ref. 10] show a decrease in the heat transfer coefficient when the lower boundary was insulated. This was evidenced by the lower Nusselt numbers at all power levels.

## **IV. RESULTS AND DISCUSSIONS FOR VERTICAL ARRANGEMENT**

### **A. FLOW VISUALIZATION**

The visualization for this experiment was tried for a chamber width of 9 mm. As was expected, there was almost no flow in the narrow gap between components and the front wall. A boundary layer-like behavior was observed on the vertical side faces of the components. The photography process was complicated because the thickness of the plane to be illuminated by the laser sheet for this chamber width was only 3 mm.

### **B. HEAT TRANSFER MEASUREMENTS**

Component surface temperature measurements were made for chamber widths of 30 mm and 9 mm (see Figure 4.1). The power level range was 0.1 W to 3.0 W. Temperatures of the top and bottom boundaries were maintained constant at 10° C. Plots of  $Nu_l$  versus  $Ra_f$  are provided for comparisons with data obtained by Benedict [Ref. 13].

#### **1. Heat Transfer Measurement for $w = 30$ mm**

Tables 17 through 28 in Appendix C compile component surface temperature and resulting nondimensional heat transfer data for this gap size with increasing power levels. The mean values of the component averaged temperatures over the nine heated components were 13° C for 0.1 W and 47° C for 3.0 W. In the range 0.1 W to 1.1 W, the lowest  $T_{avg}$  levels were on the bottom-row components

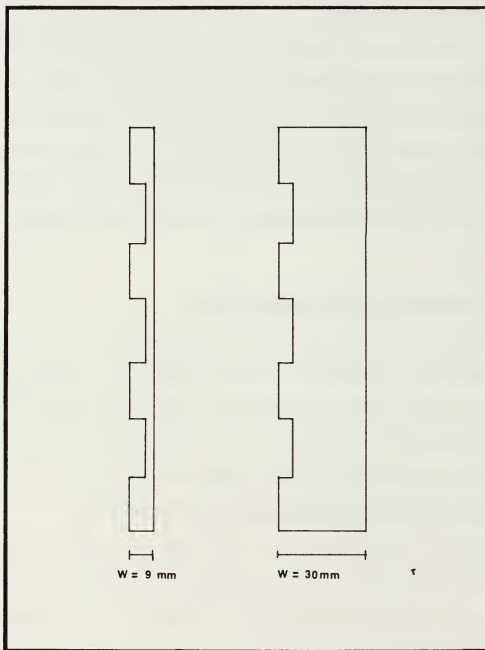
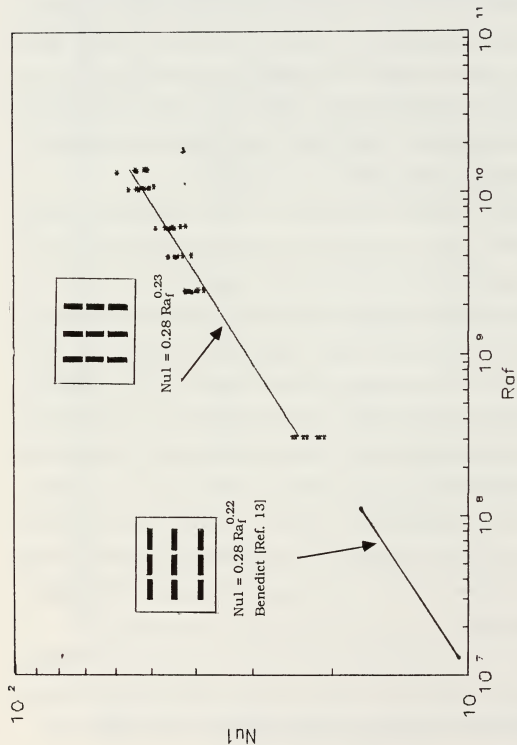


Figure 4.1 **Side View Showing the Chamber Widths  
Used in the Experiment**

(components 1, 4, and 7). The observed tendency was that temperatures on specific locations on the components in the top row were higher than those in the same location on the components in lower rows. As was pointed out by Liu, et al. [Ref. 11], the possible reason for this might be that components in the top row are in contact with warmer liquid, and the upper-row components are located in the heated wake regions of the lower rows. Additionally, the stratified fluid away from the components, which feeds fluid toward the component rows, is also at higher temperature for the upper rows.

Analyzing individual components in the middle and lower rows, for all power levels, the minimum measured temperatures were on the bottom surfaces. This trend is also supported by Liu, et al. [Ref. 9]. On the top row components, the lowest temperatures were on either one of the vertical side faces. Maximum temperatures were found generally on the component surface facing the front chamber wall. Liu, et al. [Ref. 11] obtained numerically maximum temperatures in the surfaces facing upward and attributed this to the fact that the heated flow coming off the vertical surfaces reduced the heat transfer coefficient at the component top surface. At higher power levels, oscillations in temperature changed the locations of the maximum and minimum instantaneous values, but the general tendencies found earlier were still noticed.

In Figure 4.2, a plot of  $Nu_1$  versus  $Ra_f$  is seen. Data obtained from Benedict [Ref. 13] is also plotted. A linear least squares fit to the present measurements in Figure 4.2 was performed. This is given by:



The curve fit for the horizontal arrangement is from Benedict [Ref. 13].  
 Present measurements and curve fit are for the vertical arrangement.

**Figure 4.2 Comparison of the Nondimensional Heat Transfer Measurements for Two Different Component Orientations**



$$\text{Nu}_1 = 0.28 \text{ Ra}_f^{0.23} \text{ in the range } 3 * 10^8 < \text{Ra}_f < 10^{10}$$

$$\text{and } 15 < \text{Pr} < 30.2 \quad (4.1)$$

and the one obtained with the data from Benedict [Ref. 13] was:

$$\text{Nu}_1 = 0.28 \text{ Ra}_f^{0.22} \text{ in the range } 10^7 < \text{Ra}_f < 2 * 10^8$$

$$\text{and } 15 < \text{Pr} < 30.2 \quad (4.2)$$

Comparisons between Equations 4.1 and 4.2 indicate that Nu appears not to depend on the orientation of the components in the range of  $\text{Ra}_f$  and Pr considered. This is illustrated in Figure 4.2

## 2. Heat Transfer Measurement for $w = 9 \text{ mm}$

In Tables 29 through 40 in Appendix C, component temperatures and resulting nondimensional heat transfer data are compiled. Decreasing the chamber width from 30 mm to 9 mm produced some increase in the average temperature of the components  $T_{\text{avg}}$ . This behavior was expected considering that now the surface of both top and bottom heat exchangers has been reduced to 30 percent of its former value. The mean value of the component averaged temperatures over the nine heaters for a power of 0.1 W was  $14.5^\circ \text{C}$ ,  $1.5^\circ \text{C}$  higher than the average temperature obtained with 30 mm width. For a dissipation level of 3.0 W, the mean value of the components' averaged temperature over the nine heaters was  $51^\circ \text{C}$ ,  $4.0^\circ \text{C}$  higher than the average observed for the 30 mm width. The  $T_{\text{avg}}$  value increased from the bottom to the top row, as was also found for  $w = 30 \text{ mm}$ .

Analyzing individual components on the bottom row (components 1, 4, and 7), minimum temperatures were found on the bottom surfaces.

Plots of  $Nu_1$  versus  $Ra_f$  are illustrated in Figure 4.3. The correlation obtained for this chamber width was:

$$Nu_1 = 0.073 Ra_f^{0.28} \text{ in the range } 3 \times 10^8 < Ra_f < 10^{10} \\ \text{and } 15 < Pr < 30.2 \quad (4.3)$$

This correlation indicates the expected decrease in  $Nu_1$  for the same  $Ra_f$ , when compared with Equation 4.1 for  $w = 30$  mm.

### C. TEMPERATURE FLUCTUATIONS IN STEADY STATE

Oscillations in component surface temperatures following achievement of nominally steady conditions were measured in the dissipation range of 0.1 W to 3.0 W. Three thermocouples were scanned at a rate of approximately three times per second for a period of 200 seconds. Plots of surface temperature variations were made in order to display the long-time temperature fluctuations and compare with results of Liu, et al. [Ref. 11] and Benedict [Ref. 13]. Figure 4.4 is a vertical arrangement diagram which portrays the location of the scanned thermocouples.

#### 1. Surface Temperature Fluctuations for a $w = 30$ mm

Temperature oscillations for this chamber width are illustrated in Figures 4.5 through 4.7. It was observed that at all power

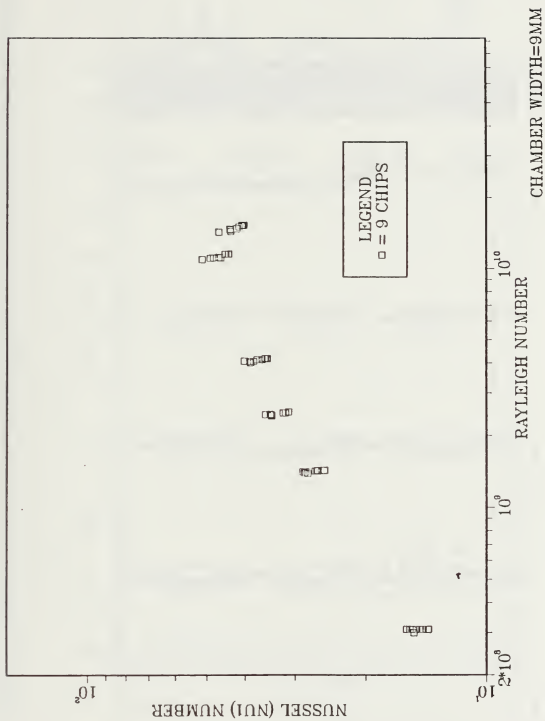


Figure 4.3 Plot of  $Nu_1$  vs.  $Ra_f$  for a Chamber Width = 9 mm



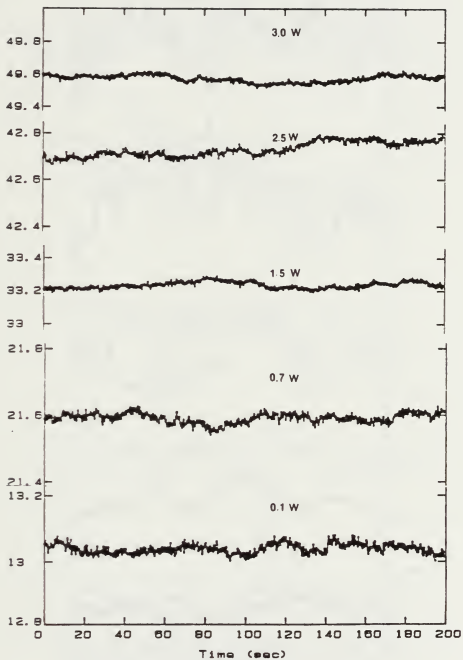
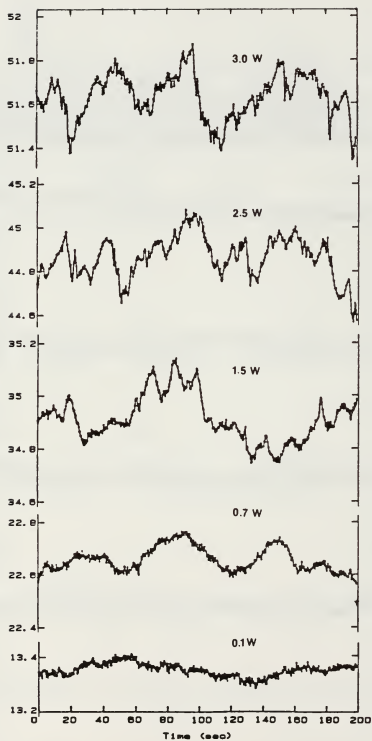
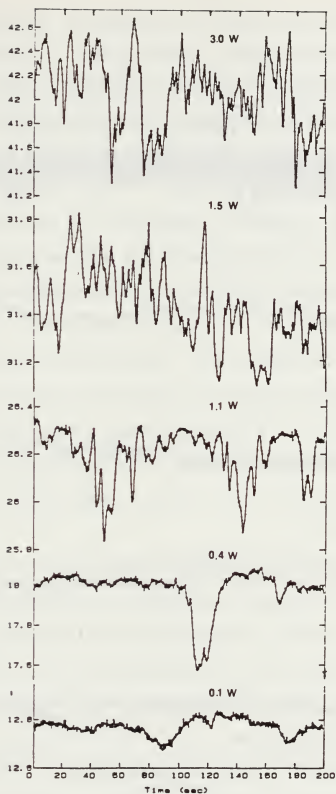


Figure 4.5 Temperature Fluctuations for Thermocouple No. 0 at Different Power Levels



**Figure 4.6 Temperature Fluctuations for Thermocouple No. 12 at Different Power Levels**



**Figure 4.7 Temperature Fluctuations for Thermocouple No. 31 at Different Power Levels**

levels considered, there were no temperature fluctuations on the components in the lower row. Benedict [Ref. 13] documented with heat transfer measurement and flow visualizations that the stagnant fluid layer above the bottom heat exchanger prevented the penetration of warmer fluid, resulting in conduction-dominated transport for the bottom row of components.

At 0.1 W, a spread in temperature of less than  $0.5^{\circ}\text{C}$  was observed between the six thermocouples that were scanned. Increasing the power level to 0.7 W, oscillation amplitudes with a mean of  $0.7^{\circ}\text{C}$  were observed in component 6. At 1.1 W, the amplitude increased to  $0.8^{\circ}\text{C}$ . Benedict [Ref. 13] found that a component at the same relative location and power level in a horizontal arrangement had almost no oscillations. At 2.5 W, oscillations of about  $1.6^{\circ}\text{C}$  were found. At 3.0 W, oscillations rose to almost  $1.7^{\circ}\text{C}$  at the same location. Benedict [Ref. 13] found at 3.1 W for the equivalent thermocouple an amplitude of  $0.85^{\circ}\text{C}$ .

## **2. Surface Temperature Fluctuations for $w = 9\text{ mm}$**

Plots of temperature oscillations are illustrated in Figures 4.8 through 4.10. At 0.1 W, no fluctuations were found in any of the thermocouples scanned. At 0.4 W, fluctuations of  $0.3^{\circ}\text{C}$  were observed in the top row components. No fluctuations were observed in the middle and bottom row components.

Increasing the power dissipation level to 0.7 W, no fluctuations were observed in either the middle or the bottom rows, but



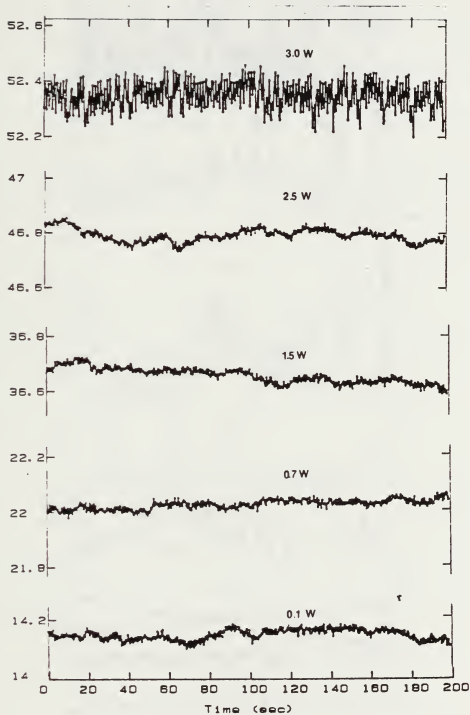
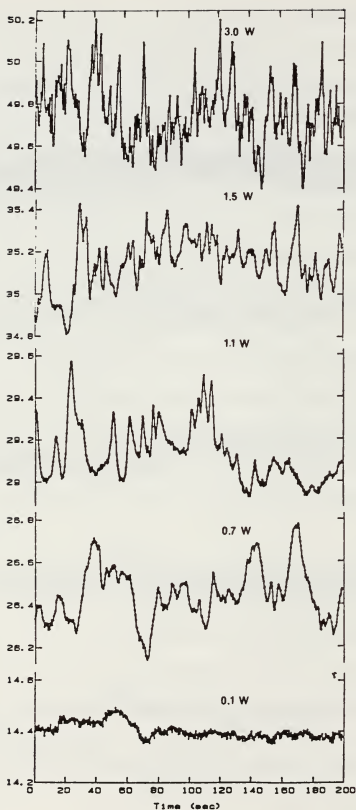


Figure 4.8 Temperature Fluctuations for Thermocouple No. 0 at Different Power Levels



**Figure 4.9 Temperature Fluctuations for Thermocouple No. 12 at Different Power Levels**

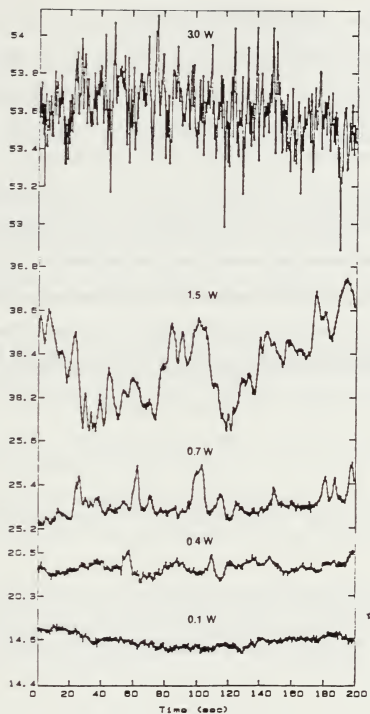


Figure 4.10 Temperature Fluctuations for Thermocouple No. 31 at Different Power Levels

fluctuations of  $0.7^{\circ}\text{C}$  were observed in the top row. At  $1.1\text{ W}$ , fluctuations in the top-row components were about  $0.9^{\circ}\text{C}$ . No fluctuations were observed at the middle and bottom rows. At  $1.5\text{ W}$ , fluctuations of  $0.2^{\circ}\text{C}$  appeared in the components in the middle row and reached values of  $1.1^{\circ}\text{C}$  in the top-row components. At  $3.0\text{ W}$ , the highest power level utilized in the experiments, fluctuation amplitudes on the top-row components were recorded at  $2.0^{\circ}\text{C}$ . It is interesting to note that no significant increase in the amplitude of the fluctuations was observed when the chamber width was changed from  $30\text{ mm}$  to  $9\text{ mm}$ . Liu, et al. [Ref. 11] calculated temperature oscillations peak to valley of  $8^{\circ}\text{C}$  for the  $9\text{ mm}$  chamber width. They attributed the increase in the oscillation amplitude to the fact that now the flow is highly confined.

## V. RECOMMENDATIONS

The design of the present chamber can be improved in many ways to give more versatility in the following experiments. The recommended changes that can be made to software and hardware include:

- Placement of the blocks can be done by screwing or attaching them to the board in a different way to the one used until now, which is bonding the chips to the board with glue. This would allow the experimenter to change a defective heater or change the orientation of the chips for a different set of experiments, using the same board and the same equipment set-up.
- To avoid the flow of dielectric liquid to the back of the chamber through the gaps between the board and the chamber walls that can alter the heat transfer results or the flow visualization, a small diameter O-ring can be used. A groove should be engraved in the board to allow the O-ring installation.
- Temperature measurements within the fluid and on the board surfaces should also be performed.
- a Fast Fourier Transform algorithm should be developed to perform frequency analysis on the surface temperature fluctuations data. In addition, improvements in the plotting programs can be made.
- With the present set-up, different combinations of heaters could be powered, row-wise or column-wise or staggered, instead of the entire array. This variation might help better to explain the heat transfer and flow characteristics of the chamber.

APPENDIX A  
SAMPLE CALCULATIONS

**A. CONVERSION OF THERMOCOUPLE VOLTAGES TO TEMPERATURES**

(Channels 0 to 60 and 71 to 76, in the data acquisition system)

$$T = D1 + D2 * Emf + D3 * Emf^2 + D4 * Emf^3 + D5 * Emf^4 \\ + D6 * Emf^5 + D7 * Emf^6 + D8 * Emf^7$$

where D1 to D9 are the calibration coefficients of the Omega thermocouples and are: 0.10086091, 25727.9, -767345.8, 7802-5596, -9247486589, 6.98E11, -2.66E13, and 3.94E14.

Calculating the temperature found in the thermocouple connected to channel 0 at 1.1 W gives:

$$Emf = 0.995E-3 \text{ V}$$

$$T = 24.48^\circ \text{ C}$$

**B. CALCULATION OF HEATER POWER**

Channels 61 to 70 in the data acquisition system are used to measure the supply voltage (61) and voltage to the heaters.

$$\text{Power} = Emf * (\text{Volt} - Emf)/R_p$$

Calculating the power dissipated by the heater #3:

$$\text{Power} = 3.408 * (4.085 - 3.408)/2.07$$

$$\text{Power} = 1.114 \text{ W}$$

## C. CALCULATION OF THE DIMENSIONLESS PARAMETERS

### 1. Calculation of the Block Faces Areas

Dimensions of the aluminum blocks are: length 24 mm, width 8 mm, and thickness 6 mm.

$$A_{\text{cen}} = 24 \text{ mm} * 8 \text{ mm} = 192 \text{ mm}^2 = 1.92\text{E-}4 \text{ m}^2$$

$$A_{\text{lef}} = 24 \text{ mm} * 6 \text{ mm} = 144 \text{ mm}^2 = 1.44\text{E-}4 \text{ m}^2$$

$$A_{\text{rig}} = 24 \text{ mm} * 6 \text{ mm} = 144 \text{ mm}^2 = 1.44\text{E-}4 \text{ m}^2$$

$$A_{\text{top}} = 6 \text{ mm} * 8 \text{ mm} = 48 \text{ mm}^2 = 4.8\text{E-}5 \text{ m}^2$$

$$A_{\text{bot}} = 6 \text{ mm} * 8 \text{ mm} = 48 \text{ mm}^2 = 4.8\text{E-}5 \text{ m}^2$$

$$A_{\text{tot}} = \Sigma A = 576 \text{ mm}^2 = 5.76\text{E-}4 \text{ m}^2$$

$$T_{\text{avg}} = \Sigma(T(I) * A(I))/A_{\text{tot}}$$

Calculating for component 3 at 1.1 W:

$$T_{\text{avg}} = (27.67 * 1.92\text{E-}4 + 25.73 * 4.8\text{E-}5 + 26.08$$

$$* 1.44\text{E-}4 + 26.69 * 4.8\text{E-}5) / 5.76\text{E-}4$$

$$T_{\text{avg}} = 26.63^\circ \text{ C}$$

## **2. Calculation of the Temperatures at the Back of the Components**

Due to problems in the placement of the thermocouples that measure the temperature at the heaters, these temperatures were calculated with a calibration curve for  $w = 30$  mm from data obtained in Benedict [Ref. 13]. This calibration cannot be applied to the case where the width of the chamber is very small. In such a case, when  $w = 9$  mm, a one-dimensional conduction analysis was applied to find the back temperature.

The best fit for the calibration points was:

$$T(K) = 14.003957 * \text{Power} + 14.517501$$

So, for 1.1 W,

$$T = 29.92^\circ \text{ C}$$

## **3. To Calculate the Conduction Losses Through the Circuit Card**

$$Q_{\text{loss}} = \Delta T / R_c = 1/N \sum (T(I) - T_b(J)) / R_c$$

$$R_c = L / kA$$

$$R_c = 19.5\text{E-}3 / (0.195 * 8\text{E-}3 * 24\text{E-}3) = 520.83 \text{ K/W}$$

$$L = 19.5\text{E-}3 \text{ m}$$

$$k = 0.195 \text{ W/m.K (plexiglass conductivity [Ref. 14])}$$

$$A = (24\text{E-}3 * 8\text{E-}3) \text{ m}^2 = 1.92\text{E-}4 \text{ m}^2$$

$$Q_{\text{loss}} = (29.92 - 17.31) / 520.83$$

$$= 0.024 \text{ W}$$



#### 4. To Find the Average Sink Temperature

Channels 58, 59, and 60 in the bottom heat exchanger and channels 61, 72, and 73 in the top heat exchanger.

$$T_{\text{sink}} = 1/N (\Sigma T_{\text{tc}} + \Sigma T_{\text{bc}})$$

$$T_{\text{sink}} = (10.05 + 10.1 + 10.02 + 10.11 + 10.12 + 10.13)/6$$

$$T_{\text{sink}} = 10.08^{\circ} \text{ C}$$

To find the net power dissipated by the heater,  $Q_{\text{net}}$ :

$$Q_{\text{net}} = \text{Power} - Q_{\text{loss}}$$

For 1.1 W and component 3:

$$Q_{\text{net}} = (1.1 - 0.024) \text{ W}$$

$$= 1.076 \text{ W}$$

To find the convection coefficient  $h$  (from Newton's law of cooling):

$$Q_{\text{net}} = h * A_{\text{tot}} * \Delta T$$

$$\Delta T = T_{\text{avg}} - T_{\text{sink}}$$

$$\Delta T = (26.63 - 10.08)^{\circ} \text{ C}$$

$$T = 16.55^{\circ} \text{ C}$$

$$h = Q_{\text{net}} / (A_{\text{tot}} * \Delta T)$$

#### 5. For 1.1 W and Component 3

$$h = 1.09 / (16.55 * 5.76 \times 10^{-4})$$

$$h = 114.342 \text{ W/m}^2 \text{ K}$$

**6. To Calculate the Thermal Conductivity of the FC-75**

$$k = (0.65 - 7.8947E-4 * T_{\text{film}})/10$$

where  $T_{\text{film}} = (T_{\text{avg}} + T_{\text{sink}})/2$ .

At 1.1 W and chip 3:

$$T_{\text{film}} = (26.63 + 10.08)^{\circ} \text{C} / 2$$

$$T_{\text{film}} = 18.35^{\circ} \text{C}$$

$$k = 0.0645 \text{ W/m K}$$

**7. To Calculate the Vertical Length Based Nusselt Number, Nu1**

$$\text{Nu1} = h * L1/k$$

$$\text{Nu1} = 114.342 * 24E-3/0.0645$$

$$\text{Nu1} = 42.54$$

**8. To Calculate the Ratio Area/Perimeter Based Nusselt Number, Nu2**

$$L2 = \Sigma(A(i)/P(i))$$

$$L2 = (24 * 8)/64 + (2 * 8 * 6)/(2 * 14) + (2 * 24 * 6)/(2 * 60)$$

$$L2 = 11.229E-3 \text{ m}$$

$$L2 = 19.905$$

**9. To Calculate the Density of the FC-75,  $\rho$  (Kg/m<sup>3</sup>)**

$$\rho = (1.825 - 0.00246 * T_{\text{film}}) * 1000$$

$$\rho = 1779.86 \text{ Kg/m}^3$$

**10. To Calculate the FC-75 Specific Heat,  $C_p$  (J/Kg K)**

$$C_p = (.241111 + 3.7037\text{E-}4 * T_{\text{film}}) * 4180$$

$$C_p = 1036.25 \text{ J/Kg K}$$

**11. To Calculate the FC-75 Viscosity,  $\nu$ (m<sup>2</sup>/s)**

$$\nu = (1.4074 - 2.964\text{E-}2 * T_{\text{film}} + 3.8018\text{E-}4$$

$$* T_{\text{film}}^2 - 2.7308\text{E-}6 * T_{\text{film}}^3 + 8.1679\text{E-}9 * T_{\text{film}}^4)\text{E-}6$$

$$\nu = .97557\text{E-}6 \text{ m}^2/\text{s}$$

**12. To Find the FC-75 Thermal Expansion Coefficient,  $\beta$ (K<sup>-1</sup>)**

$$\beta = 0.00246 / (1.825 - 0.00246 * T_{\text{film}})$$

For 1.1 W and component 3:

$$\beta = 1.382\text{E-}3 \text{ K}^{-1}$$

**13. To Calculate the FC-75 Thermal Diffusivity  $\alpha$ (m<sup>2</sup>/s)**

$$\alpha = k / \rho * C_p$$

For 1.1 W and component 3:

$$\alpha = 3.497\text{E-}8 \text{ m}^2/\text{s}$$

#### **14. To Calculate the Grashof Number**

$$\text{Gr} = g * \beta * l^3 * \Delta T / \nu^2$$

For 1.1 W and component 3:

$$\text{Gr} = 3255734.402$$

#### **15. To Calculate the Prandtl Number**

$$\text{Pr} = \nu / \alpha$$

$$\text{Pr} = 27.89$$

#### **16. To Find the Temperature Based Rayleigh Number**

$$\text{Ra} = \text{Gr} * \text{Pr}$$

For 1.1 W and component 3:

$$\text{Ra} = 9.08\text{E}7$$

#### **17. To Calculate the Flux Based Rayleigh Number**

$$\text{Ra}_f = g * B * l^4 * Q_{\text{net}} / (k * \nu * \alpha * A_{\text{tot}})$$

$$\text{Ra}_f = 3.9\text{E}9$$

## APPENDIX B

### UNCERTAINTY ANALYSIS

The uncertainty analysis was done using the method of Kline and McClintock, presented in Holman [Ref. 15]. The calculations will be done for the end values 0.1 W and 3.0 W, for a chamber width of 30 mm.

#### A. UNCERTAINTIES IN THE NET POWER ADDED TO THE FLUID

$$Q_{\text{net}} = \text{Power} - Q_{\text{loss}}$$

$$\text{Power} = \text{emf}(I) * (\text{Volt} - \text{emf}(I))/R_p$$

$$\text{Power} = f(\text{emf}(I), \text{Volt}, R_p)$$

$$\frac{\partial \text{Power}}{\partial \text{emf}(I)} = \frac{\text{Volt} - 2 \cdot \text{emf}(I)}{R_p}$$

$$\frac{\partial \text{Power}}{\partial \text{Volt}} = \frac{\text{emf}(I)}{R_p}$$

$$\frac{\partial \text{Power}}{\partial R_p} = - \frac{\text{emf}(I) \cdot (\text{Volt} - \text{emf}(I))}{R_p^2}$$

$$W_{\text{power}} = \left[ \left( \frac{\partial \text{power}}{\partial \text{emf}(I)} \right)^2 W_{\text{emf}(I)}^2 + \left( \frac{\partial \text{power}}{\partial \text{Volt}} \right)^2 W_{\text{Volt}}^2 + \left( \frac{\partial \text{power}}{\partial R_p} \right)^2 W_{R_p}^2 \right]^{\frac{1}{2}}$$

$$W_{\text{emf}} = 0.001 \text{ V}$$

(by Resolution in the reading and precision of measuring devices)

$$W_{\text{Volt}} = 0.001 \text{ V}$$

(by Resolution in the reading and precision of measuring devices)

$$W_{\text{Rp}} = 0.05 \Omega$$

(including the added resistances)

For 0.1 W and chip 3:

$$\text{emf}(I) = 1.022 \text{ V}$$

$$\text{Volt} = 1.225 \text{ V}$$

$$R_p = 2.06 \Omega$$

(measured resistance including resistances in the junctions, etc.)

$$\frac{\partial \text{Power}}{\partial \text{emf}(I)} = -0.397$$

$$\frac{\partial \text{Power}}{\partial \text{Volt}} = 0.496$$

$$\frac{\partial \text{Power}}{\partial R_p} = -0.0488$$

$$W_{\text{power}} = \left[ (-0.397)^2 \cdot (0.001)^2 + (0.496)^2 \cdot (0.001)^2 + (-0.0488)^2 \cdot (0.05)^2 \right]^{\frac{1}{2}}$$

$$W_{\text{power}} = 0.00252 \text{ W}$$

$$\frac{W_{\text{power}}}{\text{Power}} = \frac{0.00252 \text{ W}}{0.1 \text{ W}} = 2.5 \%$$

$$Q_{\text{loss}} = \frac{\Delta T}{Rc}$$

where  $\Delta T$  is the difference in temperature between the back surface of the chip and the back of the board.

$$Q = f(\Delta T, Rc)$$

$$\frac{\partial Q_{\text{loss}}}{\partial \Delta T} = \frac{1}{Rc} = \frac{Q_{\text{loss}}}{\Delta T} = \frac{1}{Rc^2}$$

For 0.1 W and component 3:

$$\frac{\partial Q_{\text{loss}}}{\partial \Delta T} = \frac{1}{520.83 \text{ K/W}} = 0.00192$$

$$\frac{\partial Q_{\text{loss}}}{\partial Rc} = -\frac{0.12^\circ \text{ K}}{(520.83)^2} = -4.424 \times 10^{-7}$$

$$W_{Q_{\text{loss}}} = \left[ \left( \frac{1}{Rc} \right)^2 W_{\Delta T} + \left( \frac{-\Delta T}{Rc^2} \right) W_{Rc} \right]$$

$$W_{\Delta T} = 10\% = 0.012^\circ \text{ C}$$

$$W_{RC} = 10\% = 52.083 \text{ K/W}$$

$$WQ_{\text{loss}} = \left[ (0.00192)^2 \cdot 0.012^2 + (-4.424 \times 10^{-7})^2 \cdot (52.083)^2 \right]^{\frac{1}{2}}$$

$$WQ_{\text{loss}} = (5.352 \times 10^{-10})^{\frac{1}{2}} = 3.258\text{E-}5$$

$$\frac{WQ_{\text{loss}}}{Q_{\text{loss}}} = 0.14 = 14\% \quad ^1$$

$$WQ_{\text{net}} = \left[ (W_{\text{power}})^2 + (WQ_{\text{loss}})^2 \right]^{\frac{1}{2}}$$

$$WQ_{\text{net}} = \left[ (0.00252)^2 + (3.258 \times 10^{-5})^2 \right]^{\frac{1}{2}}$$

$$WQ_{\text{net}} = \pm 0.025 \text{ W}$$

$$\frac{WQ_{\text{net}}}{Q_{\text{net}}} = \pm 2.5\%$$

---

<sup>1</sup>The uncertainties in the losses are relatively big, but they do not have a large effect on the final undertaking.



For 3.0 W and component 3:

$$\text{emf}(I) = 5.647 \text{ V}$$

$$\text{Volt} = 6.762$$

$$R_p = 2.06\Omega$$

$$\frac{\partial \text{Power}}{\partial \text{emf}(I)} = -2.2$$

$$\frac{\partial \text{Power}}{\partial \text{Volt}} = 2.74$$

$$\frac{\partial \text{Power}}{\partial R_p} = 1.484$$

$$W_{\text{power}} = \left[ (-2.2)^2 \cdot (0.001)^2 + (2.74)^2 \cdot (0.001)^2 + (1.484)^2 \cdot (0.05)^2 \right]^{\frac{1}{2}}$$

$$W_{\text{power}} = 0.74 \text{ W}$$

$$\frac{W_{\text{power}}}{\text{power}} = \frac{0.074}{3.0} = \pm 2.5\%$$

$$\frac{\partial Q_{\text{loss}}}{\partial \Delta T} = \frac{1}{520.83} \text{ k/w} = 0.00192$$

$$\frac{\partial Q_{\text{loss}}}{\partial R_c} = -\frac{21.68}{(520.83)^2} = -7.993\text{E-}5$$

$$WQ_{\text{loss}} = \left[ (0.00192)^2 \cdot (2.168)^2 + (-7.992 \times 10^{-5})^2 \cdot (52.083)^2 \right]^{\frac{1}{2}}$$

$$WQ_{\text{loss}} = 0.059 \text{ W}$$

$$\frac{WQ_{\text{loss}}}{Q_{\text{loss}}} = 14.14\%$$

$$WQ_{\text{net}} = \left[ (W_{\text{power}})^2 + (WQ_{\text{loss}})^2 \right]^{\frac{1}{2}}$$

$$WQ_{\text{net}} = \left[ (0.074)^2 + (0.0059)^2 \right]^{\frac{1}{2}}$$

$$WQ_{\text{net}} = \pm 0.0742 \text{ W}$$

$$\frac{WQ_{\text{net}}}{Q_{\text{net}}} = \pm 2.5\%$$

## B. UNCERTAINTY IN RAYLEIGH AND NUSSELT NUMBERS

Starting with:

$$Q_{\text{net}} = hA_{\text{tot}} (T_{\text{avg}} - T_{\text{sink}})$$

$$h = \frac{Q_{\text{net}}}{A_{\text{tot}} (T_{\text{avg}} - T_{\text{sink}})}$$

$$h = f(Q_{\text{net}}, A_{\text{tot}}, \Delta T)$$

$$\frac{\partial h}{\partial Q_{\text{net}}} = \frac{1}{A_{\text{tot}} (\Delta T)}$$

$$\frac{\partial h}{\partial A_{\text{tot}}} = \frac{Q_{\text{net}}}{A_{\text{tot}}^2 (\Delta T)}$$

$$\frac{\partial h}{\partial \Delta T} = \frac{Q_{\text{net}}}{A_{\text{tot}}^2 (\Delta T)^2}$$

for 0.1 W and component 3:

$$A_{\text{tot}} = 5.76 \times 10^{-4} \text{ m}^2 \text{ (for all components)}$$

$$\frac{\partial h}{\partial Q_{\text{net}}} = \frac{1}{(5.76 \times 10^{-4})(3.02)} = 574.87$$

$$\frac{\partial h}{\partial A_{\text{tot}}} = \frac{0.1}{(5.76 \times 10^{-4})(3.02)} = -99804.03$$

$$\frac{\partial h}{\partial \Delta T} = -\frac{0.1}{(5.76 \times 10^{-4})(3.02)^2} = -19.035$$

$$w_h = \left[ \left( \frac{\partial h}{\partial Q_{\text{net}}} \right)^2 w_{Q_{\text{net}}}^2 + \left( \frac{\partial h}{\partial A_{\text{tot}}} \right)^2 w_{A_{\text{tot}}}^2 + \left( \frac{\partial h}{\partial \Delta T} \right)^2 w_{\Delta T}^2 \right]^{\frac{1}{2}}$$

$$W_{Q_{\text{net}}} = \pm 0.0025 \text{ W}$$

$$W_L = \pm 10^{-5} \text{ m}$$

$$W_A = \left[ (10^{-5})^2 + (10^{-5})^2 \right]^{\frac{1}{2}} = 1.41 \text{E} -5 \text{ m}^2$$

$$W_{\Delta T} = \pm 1\% = 0.03^\circ \text{ C}$$

$$W_h = \left[ (574.87)^2 \cdot (0.0025)^2 + (99804)^2 \cdot (1.41 \text{E} -5)^2 + (19.035)^2 \cdot (0.03)^2 \right]^{\frac{1}{2}}$$

$$W_h = (2.065 + 0.019 + 3.260)^{\frac{1}{2}}$$

$$= \pm 2.09 \text{ W/m}^2 \text{ K}$$

$$\frac{W_h}{h} = \frac{2.09}{57.487} = \pm 3.64\%$$

For 3.0 W and component 3:

$$\frac{\partial h}{\partial Q_{\text{net}}} = \frac{1}{(5.76 \times 10^{-4})(38.38)} = 45.52$$

$$\frac{\partial h}{\partial A_{\text{tot}}} = \frac{3.0}{(5.76 \times 10^{-4})^2 (38.38)} = 235597.84$$

$$\frac{\partial h}{\partial \Delta T} = \frac{3.0}{(5.76 \times 10^{-4})(38.38)^2} = 3,536$$

$$W_h = \left[ (45.52)^2 \cdot (0.0742)^2 + (235597.8)^2 \cdot (1.41 \text{E} -5)^2 + (3.54)^2 \cdot (.38)^2 \right]^{\frac{1}{2}}$$

$$W_h = \pm 4.92 \text{ w/m}^2 \text{ K}$$

$$\frac{W_h}{h} = \frac{4.92}{135.7} = 3.63\%$$

To find the uncertainty of Nusselt Number:

$$Nu = \frac{h_L}{k}$$

$$Nu = f(h, L, k)$$

$$\frac{\partial Nu}{\partial h} = \frac{L}{k}$$

$$\frac{\partial Nu}{\partial L} = \frac{h}{k}$$

$$\frac{\partial Nu}{\partial k} = -\frac{hL}{k^2}$$

Since the thermal properties of the FC-75 (dielectric liquid) are values that depend on film temperatures, it is considered that there are no uncertainties in these values.

$$K = (0.65 - 7.89474E-4 \cdot T_{\text{film}}) / 10$$

$$T_{\text{film}} = \frac{T_{\text{avg}} + T_{\text{sink}}}{2}$$

For 0.1 W and component 3:

$$K = 0.064 \frac{\text{W}}{\text{m K}}$$

$$T_{\text{film}} = 11.51^\circ \text{C}$$

$$\frac{\partial \text{Nu}}{\partial k} = \frac{24 \times 10^{-3} \text{m}}{0.064 \text{ W/m K}} = 0.374$$

$$\frac{\partial \text{Nu}}{\partial k} = \frac{57.487}{24 \times 10^{-3}} = 2395.29$$

$$\frac{\partial \text{Nu}}{\partial k} = \frac{57.487 \times 24 \times 10^{-3}}{(0.064)^2} = 336.84$$

$$W\text{Nu} = \left[ \left( \frac{\partial \text{Nu}}{\partial h} \right)^2 W h^2 + \left( \frac{\partial \text{Nu}}{\partial L} \right)^2 W L^2 + \left( \frac{\partial \text{Nu}}{\partial k} \right)^2 W k^2 \right]^{\frac{1}{2}}$$

$$W\text{Nu} = \left[ (0.374)^2 \cdot (2.09)^2 + (2395.29)^2 \cdot (10^{-5})^2 \right]^{\frac{1}{2}}$$

$$W\text{Nu} = \pm 0.78$$

$$\frac{WNu}{Nu} = \frac{0.78}{21.55} = 0.036 = 3.6\%$$

For 3.0 W and component 3:

$$k_f = 0.0627 \frac{W}{mk}$$

$$T_{\text{film}} = 29.2^\circ \text{ C}$$

$$\frac{\partial Nu}{\partial h} = \frac{24 \times 10^{-3} m}{0.0627} = 0.382$$

$$\frac{\partial Nu}{\partial L} = \frac{135.7}{24 \times 10^{-3}} = 5654.16$$

$$WNu = \left[ (0.382)^2 \cdot (4.92)^2 + (5654.16)^2 \cdot (10^{-5})^2 \right]^{\frac{1}{2}}$$

$$WNu = \pm 1.88$$

$$\frac{WNu}{Nu} = \frac{1.88}{51.94} = 3.62\%$$

$$Ra_f = Gr_f \cdot Pr$$

$$Gr_f = \frac{g\beta L^4 Q_{\text{net}}}{k_f \nu^2 A_{\text{tot}}}$$

$$\text{Pr} = \frac{\nu}{\alpha}$$

$$\text{Gr}_f = f(g, \beta, L^4, Q_{\text{net}}, k_f, \nu^2, A_{\text{tot}})$$

Consider fluid properties without uncertainties.

$$\frac{\partial \text{Gr}_f}{\partial L^4} = \frac{g \beta Q_{\text{net}}}{k_f \nu^2 A_{\text{tot}}}$$

$$\frac{\partial \text{Gr}_f}{\partial Q_{\text{net}}} = \frac{g \beta L^4}{k_f \nu^2 A_{\text{tot}}}$$

$$\frac{\partial \text{Gr}_f}{\partial A_{\text{tot}}} = \frac{g \beta L^4 Q_{\text{net}}}{k_f \nu^2 A_{\text{tot}}^2}$$

For 0.1 W and component 3:

$$\beta = 0.00137 \text{ K}^{-1}$$

$$k_f = 0.064 \frac{\text{W}}{\text{m} \cdot \text{K}}$$

$$\nu = 1.11259\text{E-}6 \frac{\text{m}^2}{\text{s}}$$

$$\frac{\partial \text{Gr}_f}{\partial L^4} = 2.94\text{E}13$$



$$\frac{\partial \text{Gr}_f}{\partial Q_{\text{net}}} = 9.76\text{E}7$$

$$\frac{\partial \text{Gr}_f}{\partial A_{\text{tot}}} = -1.69\text{E}10$$

$$W\text{Gr}_f = \left[ \left( \frac{\partial \text{Gr}_f}{\partial L^4} \right)^2 W^2 L^4 + \left( \frac{\partial \text{Gr}_f}{\partial Q_{\text{net}}} \right)^2 W^2 Q_{\text{net}} + \left( \frac{\partial \text{Gr}_f}{\partial A_{\text{tot}}} \right)^2 W A_{\text{tot}} \right]^{\frac{1}{2}}$$

$$W\text{Gr}_f = \left[ \begin{aligned} &(2.94\text{E}13)^2 \cdot (5.5 \text{E}-10)^2 + (9.76\text{E}7)^2 \cdot (0.0025)^2 \\ &+ (1.69\text{E}10)^2 \cdot (4.8 \text{E}-7)^2 \end{aligned} \right]^{\frac{1}{2}}$$

$$W\text{Gr}_f = [2.6\text{E}8 + 5.9536\text{E}10 + 6.5\text{E}7]^{\frac{1}{2}}$$

$$W\text{Gr}_f = \pm 243569$$

$$\frac{W_{\text{Gr}_f}}{\text{Gr}_f} = \frac{243569}{9.67\text{E}6} = 2.5\%$$

$$W_{\text{Ra}_f} = 2.5\%$$

For 3.0 W and component 3:

$$\beta = 0.014 \text{ K}^{-1}$$

$$v = 0.80402 \times 10^{-6} \frac{\text{m}^2}{\text{s}}$$

$$k_f = 0.0627 \frac{\text{W}}{\text{m.K}}$$

$$\frac{\partial \text{Gr}_f}{\partial L^4} = 17.6\text{E}15$$

$$\frac{\partial \text{Gr}_f}{\partial Q_{\text{net}}} = 19.5\text{E}7$$

$$\frac{\partial \text{Gr}_f}{\partial A_{\text{tot}}} = 1.0\text{E}12$$

$$W\text{Gr}_f = \left[ (17.6\text{E}15)^2 \cdot (5.5\text{E}-10)^2 + (19.5\text{E}7)^2 \cdot (0.0742)^2 + (1.0\text{E}12)^2 \cdot (4.8\text{E}-7)^2 \right]^{\frac{1}{2}}$$

$$W\text{Gr}_f = [9.3\text{E}13 + 2.09\text{E}14 + 2.38\text{E}11]^{\frac{1}{2}}$$

$$\frac{W\text{Gr}_f}{\text{Gr}_f} = \frac{17405183}{584920180} = 2.9\%$$

$$W\text{Ra}_f = 2.9\%$$

# APPENDIX C

## TABLES

TABLE 1

### TEMPERATURE DATA FOR INPUT POWER 0.1 W BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08021455

AMBIENT TEMP : 24.3 C  
VOLTMETER READING : 1.025 V  
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	17.46E+00	17.48E+00	17.48E+00	17.47E+00	17.54E+00	18.04E+00
POWER (WATTS):	10.01E-02					
CHIP NO2:	17.40E+00	17.44E+00	17.47E+00	17.41E+00	17.47E+00	17.96E+00
POWER (WATTS):	10.00E-02					
CHIP NO3:	17.15E+00	17.08E+00	17.16E+00	17.22E+00	17.29E+00	17.61E+00
POWER (WATTS):	99.84E-03					
CHIP NO4:	17.57E+00	17.56E+00	17.44E+00	15.60E+00	17.48E+00	17.89E+00
POWER (WATTS):	98.84E-03					
CHIP NO5:	17.48E+00	17.62E+00	17.56E+00	17.51E+00	17.58E+00	17.92E+00
POWER (WATTS):	99.24E-03					
CHIP NO6:	22.68E+00	17.39E+00	17.43E+00	17.38E+00	17.55E+00	18.42E+00
POWER (WATTS):	99.12E-03					
CHIP NO7:	17.59E+00	17.62E+00	17.60E+00	17.55E+00	17.74E+00	18.32E+00
POWER (WATTS):	10.04E-02					
CHIP NO8:	17.58E+00	17.64E+00	17.67E+00	17.58E+00	17.60E+00	18.47E+00
POWER (WATTS):	10.07E-02					
CHIP NO9:	17.33E+00	17.15E+00	17.34E+00	17.30E+00	17.36E+00	17.82E+00
POWER (WATTS):	99.32E-03					

AVERAGE HEAT EXCHANGERS TEMPERATURES:  
BOTTOM: 10.01E+00  
TOP: 19.97E+00

BACK PLANE TEMPERATURES ARE :

T(55): 17.81E+00  
T(56): 18.09E+00  
T(57): 17.54E+00  
T(72): 18.33E+00  
T(73): 18.43E+00  
T(74): 18.91E+00  
T(75): 18.07E+00  
T(76): 18.40E+00  
T(77): 18.29E+00

TABLE 2

**TEMPERATURE DATA FOR INPUT POWER 0.7 W  
BOTTOM BOUNDARY AT 20° C**

RESULTS ARE STORED IN FILE: 08021717

AMBIENT TEMP : 24.4 C  
VOLTMEETER READING : 3.218 V  
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	24.74E+00	24.02E+00	23.96E+00	24.00E+00	24.09E+00	27.01E+00
POWER (WATTS):	70.97E-02					
CHIP NO2:	24.71E+00	23.81E+00	23.96E+00	23.54E+00	23.80E+00	26.56E+00
POWER (WATTS):	70.93E-02					
CHIP NO3:	23.83E+00	23.69E+00	23.59E+00	23.55E+00	23.60E+00	25.11E+00
POWER (WATTS):	70.79E-02					
CHIP NO4:	24.30E+00	23.71E+00	23.60E+00	20.65E+00	23.60E+00	25.74E+00
POWER (WATTS):	70.09E-02					
CHIP NO5:	24.26E+00	23.46E+00	23.44E+00	23.37E+00	23.69E+00	25.46E+00
POWER (WATTS):	70.38E-02					
CHIP NO6:	26.78E+00	24.05E+00	23.44E+00	23.51E+00	24.08E+00	27.57E+00
POWER (WATTS):	70.26E-02					
CHIP NO7:	24.96E+00	24.47E+00	24.02E+00	23.81E+00	24.14E+00	27.58E+00
POWER (WATTS):	71.19E-02					
CHIP NO8:	24.27E+00	24.14E+00	24.07E+00	23.85E+00	23.79E+00	29.43E+00
POWER (WATTS):	71.40E-02					
CHIP NO9:	23.90E+00	23.70E+00	23.62E+00	23.50E+00	23.44E+00	26.70E+00
POWER (WATTS):	70.84E-02					

AVERAGE HEAT EXCHANGERS TEMPERATURES:

BOTTOM: 10.00E+00  
TOP: 20.00E+00

BACK PLANE TEMPERATURES ARE :

T(55): 20.83E+00  
T(56): 21.22E+00  
T(57): 20.72E+00  
T(72): 21.38E+00  
T(73): 21.10E+00  
T(74): 21.50E+00  
T(75): 21.03E+00  
T(76): 21.18E+00  
T(77): 21.23E+00

TABLE 3

**TEMPERATURE DATA FOR INPUT POWER 1.5 W  
BOTTOM BOUNDARY AT 20° C**

RESULTS ARE STORED IN FILE: 08030205

AMBIENT TEMP : 24.4 C  
VOLTMETER READING : 4.7082 V  
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	33.28E+00	31.29E+00	31.67E+00	31.63E+00	31.81E+00	37.53E+00
POWER (WATTS):	15.17E-01					
CHIP N02:	33.22E+00	31.21E+00	31.50E+00	30.68E+00	31.25E+00	36.83E+00
POWER (WATTS):	15.16E-01					
CHIP N03:	31.23E+00	31.26E+00	30.99E+00	30.76E+00	30.63E+00	34.16E+00
POWER (WATTS):	15.13E-01					
CHIP N04:	33.06E+00	31.52E+00	31.54E+00	27.88E+00	31.60E+00	35.83E+00
POWER (WATTS):	14.98E-01					
CHIP N05:	32.56E+00	30.25E+00	30.60E+00	30.44E+00	31.30E+00	34.65E+00
POWER (WATTS):	15.04E-01					
CHIP N06:	20.87E+00	32.79E+00	30.75E+00	31.13E+00	32.43E+00	43.50E+00
POWER (WATTS):	15.01E-01					
CHIP N07:	33.79E+00	32.54E+00	31.83E+00	31.29E+00	31.97E+00	38.83E+00
POWER (WATTS):	15.21E-01					
CHIP N08:	32.46E+00	31.64E+00	31.72E+00	31.46E+00	31.25E+00	43.11E+00
POWER (WATTS):	15.26E-01					
CHIP N09:	31.47E+00	31.25E+00	31.12E+00	30.80E+00	31.01E+00	37.41E+00
POWER (WATTS):	15.14E-01					

AVERAGE HEAT EXCHANGERS TEMPERATURES:  
BOTTOM: 10.09E+00  
TOP: 20.04E+00

BACK PLANE TEMPERATURES ARE :

T(55): 23.97E+00  
T(56): 24.51E+00  
T(57): 25.06E+00  
T(72): 24.93E+00  
T(73): 24.57E+00  
T(74): 24.85E+00  
T(75): 25.10E+00  
T(76): 24.49E+00  
T(77): 24.61E+00

TABLE 4

**TEMPERATURE DATA FOR INPUT POWER 3.0 W  
BOTTOM BOUNDARY AT 20° C**

RESULTS ARE STORED IN FILE: 03041705

AMBIENT TEMP : 24.5 C  
VOLTMETER READING : 6.601 V  
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	49.47E+00	45.65E+00	46.44E+00	46.13E+00	45.76E+00	56.26E+00
POWER (WATTS):	29.74E-01					
CHIP NO2:	48.99E+00	45.37E+00	46.33E+00	44.51E+00	46.02E+00	56.02E+00
POWER (WATTS):	29.73E-01					
CHIP NO3:	44.62E+00	45.57E+00	45.04E+00	44.58E+00	44.60E+00	51.20E+00
POWER (WATTS):	29.68E-01					
CHIP NO4:	49.59E+00	46.17E+00	46.77E+00	42.62E+00	46.97E+00	54.89E+00
POWER (WATTS):	29.38E-01					
CHIP NO5:	48.69E+00	43.92E+00	45.19E+00	44.75E+00	46.43E+00	52.53E+00
POWER (WATTS):	29.51E-01					
CHIP NO6:	37.80E+00	48.64E+00	45.04E+00	45.78E+00	47.85E+00	68.62E+00
POWER (WATTS):	29.40E-01					
CHIP NO7:	51.18E+00	48.27E+00	47.48E+00	46.51E+00	47.28E+00	58.60E+00
POWER (WATTS):	29.62E-01					
CHIP NO8:	48.09E+00	47.05E+00	47.09E+00	46.58E+00	45.99E+00	67.94E+00
POWER (WATTS):	29.91E-01					
CHIP NO9:	44.97E+00	45.78E+00	45.57E+00	45.11E+00	44.78E+00	58.25E+00
POWER (WATTS):	29.69E-01					

AVERAGE HEAT EXCHANGERS TEMPERATURES:

BOTTOM: 10.98E+00  
TOP: 20.08E+00

BACK PLANE TEMPERATURES ARE :

T(55): 31.46E+00  
T(56): 32.62E+00  
T(57): 34.30E+00  
T(72): 33.38E+00  
T(73): 32.78E+00  
T(74): 33.27E+00  
T(75): 33.99E+00  
T(76): 32.43E+00  
T(77): 32.42E+00

TABLE 5

**REDUCED DATA FOR INPUT POWER 0.1 W  
BOTTOM BOUNDARY AT 20° C**

THE RAW Enf DATA ARE FROM THE FILE: 08021455  
THE POWER SETTING PER CHIP WAS: 0.1 W

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	99.93E-03	74.63E-01	29.10E-01	13.42E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 139.72E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :134.16E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 405.58E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 458.54E-05			
2	99.84E-03	74.15E-01	29.26E-01	13.50E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 138.74E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :135.03E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 405.97E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 458.97E-05			
3	99.64E-03	71.59E-01	30.24E-01	13.99E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 133.57E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :139.86E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.97E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 459.86E-05			
4	98.64E-03	70.22E-01	30.52E-01	14.26E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 130.83E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :142.58E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 399.28E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 464.52E-05			
5	99.04E-03	75.15E-01	28.64E-01	13.32E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 140.78E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :133.23E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.22E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 462.64E-05			
6	98.92E-03	91.61E-01	23.49E-01	10.93E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 174.75E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :109.29E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 410.50E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 463.23E-05			
7	10.02E-02	75.85E-01	28.72E-01	13.20E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 142.19E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :132.01E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 408.40E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 457.14E-05			
8	10.05E-02	75.98E-01	28.75E-01	13.18E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 142.45E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :131.78E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 409.59E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 455.89E-05			
9	99.72E-03	73.00E-01	29.68E-01	13.72E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 136.42E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :137.15E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 404.94E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 459.52E-05			

TABLE 6

**REDUCED DATA FOR INPUT POWER 0.7 W  
BOTTOM BOUNDARY AT 20° C**

THE RAW Emf DATA ARE FROM THE FILE: 08021717  
THE POWER SETTING PER CHIP WAS: 0.7 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	70.20E-02	14.24E+00	10.76E+00	70.34E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 297.08E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :703.04E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 308.85E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 231.59E-04			
2	70.16E-02	14.08E+00	10.88E+00	71.16E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 283.28E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :711.21E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 308.10E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 231.71E-04			
3	70.03E-02	13.66E+00	11.18E+00	73.32E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 273.69E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :732.84E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 306.03E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 232.17E-04			
4	69.32E-02	13.10E+00	11.54E+00	76.47E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 260.80E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :764.36E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 301.00E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 234.54E-04			
5	69.61E-02	13.71E+00	11.08E+00	73.06E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 274.81E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :730.23E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 304.37E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.57E-04			
6	69.49E-02	14.67E+00	10.34E+00	68.30E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 297.03E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :682.63E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 307.22E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.95E-04			
7	70.42E-02	14.32E+00	10.73E+00	69.95E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 288.95E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :699.10E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 310.07E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 230.88E-04			
8	70.63E-02	14.06E+00	10.96E+00	71.25E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 282.84E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :712.17E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 310.07E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 230.19E-04			
9	70.07E-02	13.67E+00	11.18E+00	73.27E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 273.90E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :732.34E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 306.28E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 232.01E-04			



TABLE 7

**REDUCED DATA FOR INPUT POWER 1.5 W  
BOTTOM BOUNDARY AT 20° C**

THE RAW Enf DATA ARE FROM THE FILE: 08030205  
THE POWER SETTING PER CHIP WAS: 1.5 WATTS

CHIP	QNET(N)	Tavg-Ts	Nu	%UNC IN Nu
1	15.00E-01	22.08E+00	14.90E+00	45.39E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 484.85E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :453.37E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 722.22E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.19E-04			
2	14.99E-01	21.73E+00	15.13E+00	46.13E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 475.36E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :460.71E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 719.11E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.28E-04			
3	14.96E-01	20.92E+00	15.68E+00	47.92E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 453.60E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :478.68E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 711.25E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.71E-04			
4	14.81E-01	21.04E+00	15.43E+00	47.63E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 457.00E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :475.76E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 705.05E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 228.02E-04			
5	14.87E-01	21.15E+00	15.42E+00	47.39E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 459.81E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :473.39E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 708.81E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.07E-04			
6	14.84E-01	17.77E+00	18.26E+00	56.38E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 372.79E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :563.37E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 680.72E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.65E-04			
7	15.04E-01	22.33E+00	14.78E+00	44.90E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 491.49E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :448.39E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 726.23E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 224.56E-04			
8	15.09E-01	21.76E+00	15.20E+00	46.06E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 476.17E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :460.08E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 723.92E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 223.86E-04			
9	14.97E-01	21.07E+00	15.58E+00	47.58E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 457.63E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :475.23E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 712.92E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.59E-04			

TABLE 8

# **REDUCED DATA FOR INPUT POWER 3.0 W** **BOTTOM BOUNDARY AT 20° C**

THE RAW Enf DATA ARE FROM THE FILE: 08041705  
 THE POWER SETTING PER CHIP WAS: 3.0 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	ZUNC IN Nu
1	29.42E-01	36.28E+00	17.97E+00	27.67E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 936.63E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :276.00E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 168.28E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.60E-04			
2	29.41E-01	35.68E+00	18.25E+00	28.13E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 915.94E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :280.60E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 167.20E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.65E-04			
3	29.36E-01	33.82E+00	19.20E+00	29.67E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 852.28E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :296.05E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 163.66E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 195.00E-04			
4	29.06E-01	35.66E+00	18.05E+00	28.14E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 915.27E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :280.75E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 165.19E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 196.99E-04			
5	29.19E-01	35.27E+00	18.32E+00	28.46E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 901.62E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :283.89E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 165.19E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 196.17E-04			
6	29.08E-01	32.37E+00	19.95E+00	30.99E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 804.05E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :309.31E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 159.62E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 196.89E-04			
7	29.50E-01	37.54E+00	17.42E+00	26.74E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 981.44E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :266.69E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 170.99E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.07E-04			
8	29.59E-01	36.23E+00	18.09E+00	27.71E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 934.88E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :276.38E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 169.15E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 193.51E-04			
9	29.37E-01	34.23E+00	18.98E+00	29.32E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 866.10E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :292.51E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 164.42E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 194.95E-04			

TABLE 9

# TEMPERATURE DATA FOR INPUT POWER 0.1 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08221255

AMBIENT TEMP WAS: 23.0 C  
VOLTMETER READING WAS: 1.2134 V  
BATH TEMP WAS: 10 C-INSUL

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	15.82E+00	15.85E+00	15.85E+00	15.82E+00	15.87E+00	16.36E+00
POWER (WATTS):	10.08E-02					
CHIP NO2:	15.92E+00	15.95E+00	15.98E+00	15.87E+00	15.95E+00	16.44E+00
POWER (WATTS):	10.07E-02					
CHIP NO3:	15.71E+00	15.66E+00	15.78E+00	15.82E+00	15.86E+00	16.14E+00
POWER (WATTS):	10.05E-02					
CHIP NO4:	15.77E+00	15.83E+00	15.72E+00	15.64E+00	15.71E+00	16.12E+00
POWER (WATTS):	99.49E-03					
CHIP NO5:	15.77E+00	15.87E+00	15.84E+00	15.77E+00	15.85E+00	16.20E+00
POWER (WATTS):	99.89E-03					
CHIP NO6:	17.92E+00	15.73E+00	15.77E+00	15.71E+00	12.78E+00	16.59E+00
POWER (WATTS):	99.74E-03					
CHIP NO7:	15.75E+00	15.79E+00	15.75E+00	15.71E+00	15.84E+00	16.41E+00
POWER (WATTS):	10.11E-02					
CHIP NO8:	15.85E+00	15.86E+00	15.91E+00	15.82E+00	15.83E+00	16.56E+00
POWER (WATTS):	10.14E-02					
CHIP NO9:	15.56E+00	15.49E+00	15.62E+00	15.59E+00	15.64E+00	16.15E+00
POWER (WATTS):	10.05E-02					

HEAT EXCHANGERS TEMPERATURES:

BOTTOM:	RIGHT	LEFT
TOP:	15.97E+00	15.97E+00
	10.20E+00	96.30E-01

BACK PLANE TEMPERATURES ARE :

T(55): 15.01E+00  
T(56): 15.41E+00  
T(57): 16.01E+00  
T(72): 16.73E+00  
T(73): 16.78E+00  
T(74): 17.24E+00  
T(75): 16.42E+00  
T(76): 16.75E+00  
T(77): 16.69E+00

TABLE 10

**TEMPERATURE DATA FOR INPUT POWER 0.7 W  
BOTTOM BOUNDARY INSULATED**

THESE RESULTS ARE STORED IN FILE: 0822257

AMBIENT TEMP WAS: 21.7 C  
VOLTMETER READING WAS: 3.22 V  
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	23.67E+00	22.96E+00	22.84E+00	22.84E+00	22.85E+00	25.39E+00
POWER (WATTS):	70.88E-02					
CHIP N02:	23.52E+00	22.57E+00	22.76E+00	22.30E+00	22.68E+00	25.39E+00
POWER (WATTS):	70.83E-02					
CHIP N03:	22.90E+00	22.62E+00	22.51E+00	22.47E+00	22.24E+00	24.00E+00
POWER (WATTS):	70.63E-02					
CHIP N04:	23.46E+00	22.91E+00	22.73E+00	22.17E+00	22.67E+00	24.75E+00
POWER (WATTS):	69.99E-02					
CHIP N05:	23.20E+00	22.20E+00	22.27E+00	22.14E+00	22.60E+00	24.21E+00
POWER (WATTS):	70.28E-02					
CHIP N06:	26.26E+00	22.78E+00	22.23E+00	22.30E+00	18.88E+00	26.38E+00
POWER (WATTS):	70.15E-02					
CHIP N07:	23.85E+00	23.15E+00	22.80E+00	22.60E+00	22.93E+00	25.70E+00
POWER (WATTS):	71.09E-02					
CHIP N08:	23.17E+00	22.97E+00	22.85E+00	22.70E+00	22.60E+00	26.66E+00
POWER (WATTS):	71.30E-02					
CHIP N09:	22.70E+00	22.48E+00	22.43E+00	22.26E+00	22.24E+00	25.53E+00
POWER (WATTS):	70.72E-02					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	LEFT
BOTTOM:	17.35E+00	17.36E+00
TOP:	10.28E+00	97.63E-01

BACK PLANE TEMPERATURES ARE :

T(55): 19.34E+00  
T(56): 19.81E+00  
T(57): 19.74E+00  
T(72): 20.01E+00  
T(73): 71.30E-01  
T(74): 19.99E+00  
T(75): 19.59E+00  
T(76): 19.76E+00  
T(77): 19.88E+00

TABLE 11

# TEMPERATURE DATA FOR INPUT POWER 1.1 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 00231010

AMBIENT TEMP WAS: 21.33 C  
VOLTMETER READING WAS: 4.00 V  
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	28.35E+00	26.73E+00	27.12E+00	27.11E+00	27.13E+00	30.82E+00
POWER (WATTS):	10.96E-01					
CHIP N02:	28.16E+00	26.70E+00	26.93E+00	26.29E+00	26.90E+00	30.97E+00
POWER (WATTS):	10.95E-01					
CHIP N03:	26.96E+00	26.97E+00	26.70E+00	26.57E+00	26.26E+00	28.94E+00
POWER (WATTS):	10.93E-01					
CHIP N04:	28.21E+00	27.02E+00	27.14E+00	26.29E+00	27.07E+00	30.17E+00
POWER (WATTS):	10.82E-01					
CHIP N05:	27.75E+00	26.13E+00	26.25E+00	26.09E+00	26.86E+00	29.20E+00
POWER (WATTS):	10.87E-01					
CHIP N06:	27.17E+00	27.20E+00	26.33E+00	26.45E+00	25.80E+00	32.61E+00
POWER (WATTS):	10.84E-01					
CHIP N07:	28.55E+00	27.60E+00	27.07E+00	26.77E+00	27.15E+00	31.29E+00
POWER (WATTS):	10.99E-01					
CHIP N08:	27.55E+00	26.93E+00	27.08E+00	26.92E+00	26.57E+00	32.87E+00
POWER (WATTS):	11.02E-01					
CHIP N09:	26.81E+00	26.65E+00	26.59E+00	26.36E+00	26.23E+00	31.29E+00
POWER (WATTS):	10.93E-01					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	LEFT
BOTTOM:	18.43E+00	18.43E+00
TOP:	10.21E+00	97.25E-01

BACK PLANE TEMPERATURES ARE :

T(55): 21.49E+00  
T(56): 22.00E+00  
T(57): 22.27E+00  
T(72): 22.32E+00  
T(73): 21.94E+00  
T(74): 22.22E+00  
T(75): 22.04E+00  
T(76): 21.97E+00  
T(77): 22.12E+00

TABLE 12

# TEMPERATURE DATA FOR INPUT POWER 3.0 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08231310

AMBIENT TEMP WAS: 23 C  
VOLTMETER READING WAS: 4.00 V  
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	54.28E+00	49.66E+00	50.72E+00	50.63E+00	50.34E+00	59.54E+00
POWER (WATTS):		30.12E-01				
CHIP NO2:	53.84E+00	49.73E+00	50.52E+00	48.65E+00	50.06E+00	60.06E+00
POWER (WATTS):		30.11E-01				
CHIP NO3:	50.25E+00	50.25E+00	49.56E+00	49.03E+00	47.98E+00	55.22E+00
POWER (WATTS):		30.06E-01				
CHIP NO4:	53.66E+00	49.90E+00	50.54E+00	48.37E+00	50.35E+00	58.19E+00
POWER (WATTS):		29.77E-01				
CHIP NO5:	52.76E+00	47.84E+00	48.71E+00	48.29E+00	49.81E+00	55.75E+00
POWER (WATTS):		29.89E-01				
CHIP NO6:	55.76E+00	51.99E+00	48.65E+00	49.14E+00	50.78E+00	70.28E+00
POWER (WATTS):		29.78E-01				
CHIP NO7:	55.44E+00	51.67E+00	50.76E+00	50.15E+00	50.57E+00	60.78E+00
POWER (WATTS):		30.21E-01				
CHIP NO8:	52.46E+00	51.07E+00	51.00E+00	50.88E+00	50.31E+00	67.37E+00
POWER (WATTS):		30.30E-01				
CHIP NO9:	50.77E+00	50.34E+00	49.91E+00	49.40E+00	49.60E+00	51.43E+00
POWER (WATTS):		30.06E-01				

HEAT EXCHANGERS TEMPERATURES:	RIGHT	LEFT
BOTTOM:	21.94E+00	21.96E+00
TOP:	11.02E+00	98.81E-01

BACK PLANE TEMPERATURES ARE :

T(55): 32.74E+00  
T(56): 34.26E+00  
T(57): 36.45E+00  
T(72): 35.41E+00  
T(73): 34.76E+00  
T(74): 35.18E+00  
T(75): 35.96E+00  
T(76): 34.28E+00  
T(77): 34.30E+00

TABLE 13

**REDUCED DATA FOR INPUT POWER 0.1 W  
BOTTOM BOUNDARY INSULATED**

THE RAW Emf DATA ARE FROM THE FILE: 08221255  
THE POWER SETTING PER CHIP WAS: 0.1 WATTS

CHIP	GNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	10.06E-02	59.19E-01	35.91E-01	16.93E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 108.69E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :169.28E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 401.14E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 394.13E-05			
2	10.05E-02	60.09E-01	36.31E-01	16.67E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 110.46E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :166.74E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 401.11E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 394.58E-05			
3	10.03E-02	58.46E-01	37.24E-01	17.14E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 107.28E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :171.38E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 399.54E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 395.38E-05			
4	99.33E-03	58.11E-01	37.11E-01	17.24E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 106.58E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :172.43E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 395.51E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 399.24E-05			
5	99.73E-03	58.84E-01	36.79E-01	17.03E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 108.02E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :170.27E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 397.44E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 397.65E-05			
6	99.58E-03	63.05E-01	34.29E-01	15.89E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 116.29E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :158.90E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 398.81E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 398.24E-05			
7	10.09E-02	58.34E-01	37.56E-01	17.17E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 107.04E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :171.73E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 402.00E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 392.90E-05			
8	10.12E-02	59.41E-01	36.98E-01	16.87E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 109.12E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :168.66E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.56E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 391.87E-05			
9	10.04E-02	56.68E-01	38.43E-01	17.68E-01
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 103.80E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :176.77E-02			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 398.95E-04			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 395.13E-05			

TABLE 14

**REDUCED DATA FOR INPUT POWER 0.7 W  
BOTTOM BOUNDARY INSULATED**

THE RAN Emf DATA ARE FROM THE FILE: 08222257  
THE POWER SETTING PER CHIP WAS: 0.7 WATTS

CHIP	QNET(W)	Tavg-Ts	h <sub>u</sub>	%UNC IN h <sub>u</sub>
1	70.13E-02	13.10E+00	11.67E+00	76.47E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 261.03E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :764.35E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 304.66E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 234.56E-04			
2	70.07E-02	12.85E+00	11.89E+00	77.95E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 255.36E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :779.20E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 303.54E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 234.75E-04			
3	69.94E-02	12.59E+00	12.11E+00	79.57E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 249.47E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :795.34E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 302.04E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 235.21E-04			
4	69.24E-02	12.82E+00	11.78E+00	78.16E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 254.59E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :781.28E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 299.83E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 237.56E-04			
5	69.53E-02	12.54E+00	12.08E+00	79.88E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 248.36E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :798.47E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 300.13E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 236.58E-04			
6	69.40E-02	13.34E+00	11.35E+00	75.14E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 266.31E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :751.07E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 302.30E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 237.02E-04			
7	70.34E-02	13.12E+00	11.70E+00	76.40E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 261.31E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :763.62E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 305.62E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.86E-04			
8	70.55E-02	12.88E+00	11.95E+00	77.82E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 255.86E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :777.86E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 305.69E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 233.16E-04			
9	69.97E-02	12.44E+00	12.26E+00	80.54E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 246.04E-03			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :805.10E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 301.64E-03			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 235.11E-04			



TABLE 15

# REDUCED DATA FOR INPUT POWER 1.1 W BOTTOM BOUNDARY INSULATED

THE RAW Emf DATA ARE FROM THE FILE: 08231010  
THE POWER SETTING PER CHIP WAS: 1.1 WATTS

CHIP	QNET(W)	Tavg-Ts	Hu	%UNC IN Nu
1	10.84E-01	17.53E+00	13.52E+00	57.17E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 365.80E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :571.25E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 494.53E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 226.98E-04				
2	10.83E-01	17.19E+00	13.77E+00	58.29E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 357.49E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :582.43E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 492.30E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.14E-04				
3	10.81E-01	16.77E+00	14.09E+00	59.75E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 347.17E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :597.04E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 489.01E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.58E-04				
4	10.70E-01	17.30E+00	13.52E+00	57.93E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 350.14E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :578.80E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 487.09E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 229.85E-04				
5	10.75E-01	16.78E+00	14.00E+00	59.71E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 347.42E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :596.67E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 485.30E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 228.88E-04				
6	10.73E-01	16.70E+00	14.03E+00	60.00E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 345.45E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :599.56E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 484.82E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 229.37E-04				
7	10.87E-01	17.61E+00	13.50E+00	56.91E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 367.76E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :568.68E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 495.47E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 226.30E-04				
8	10.90E-01	17.22E+00	13.85E+00	58.21E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 358.03E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :581.69E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 495.81E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.59E-04				
9	10.81E-01	16.61E+00	14.23E+00	60.32E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 343.28E-03				
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :602.77E-03				
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 488.34E-03				
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.49E-04				

TABLE 16

# **REDUCED DATA FOR INPUT POWER 3.0 W** **BOTTOM BOUNDARY INSULATED**

THE RAW Emf DATA ARE FROM THE FILE: 08231310  
 THE POWER SETTING PER CHIP WAS: 3.0 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	29.78E-01	41.31E+00	16.01E+00	24.31E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 110.90E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :242.30E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 177.54E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 202.57E-04			
2	29.77E-01	40.60E+00	16.28E+00	24.74E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 108.25E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :246.54E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 176.18E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 202.65E-04			
3	29.72E-01	39.13E+00	16.84E+00	25.66E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 102.84E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :255.82E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 173.21E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 203.01E-04			
4	29.42E-01	40.51E+00	16.12E+00	24.79E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 107.92E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :247.08E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 173.98E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 205.02E-04			
5	29.55E-01	39.52E+00	16.59E+00	25.41E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 104.27E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :253.28E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 172.94E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 204.15E-04			
6	29.44E-01	41.15E+00	15.89E+00	24.42E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 110.27E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :243.29E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 175.19E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 204.93E-04			
7	29.87E-01	41.77E+00	15.89E+00	24.05E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 112.63E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :239.64E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 178.94E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 201.94E-04			
8	29.96E-01	40.95E+00	16.25E+00	24.53E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 109.55E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :244.43E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 177.96E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 201.34E-04			
9	29.72E-01	39.63E+00	16.64E+00	25.34E-02
	TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 104.65E-02			
	% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :252.60E-03			
	FLUX BASED RAYLEIGH NUMBER * E-8 IS: 174.11E-02			
	% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 203.00E-04			

TABLE 17

**TEMPERATURE DATA FOR INPUT POWER 0.1 W**  
**CHAMBER WIDTH = 30 mm**

RESULTS ARE STORED IN FILE: 10161810

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 24.33  
 BATH TEMP : 10 C-10 C

	TEMPERATURE READINGS IN DEGREES CELSIUS					
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	12.806	12.761	12.736	12.771	12.616	15.431
POWER (WATTS):	.0983					
CHIP N02:	12.954	12.894	12.591	12.861	12.816	15.438
POWER (WATTS):	.099					
CHIP N03:	13.099	12.956	00.000	12.986	13.076	15.451
POWER (WATTS):	.0996					
CHIP N04:	12.764	12.731	12.536	12.574	12.484	15.441
POWER (WATTS):	.0990					
CHIP N05:	12.831	12.894	12.836	12.824	12.801	15.446
POWER (WATTS):	.0993					
CHIP N06:	13.019	12.914	12.979	11.858	12.746	15.448
POWER (WATTS):	.0995					
CHIP N07:	12.689	12.686	12.706	12.684	12.559	15.445
POWER (WATTS):	.0992					
CHIP N08:	13.039	12.941	12.966	00.000	12.901	15.442
POWER (WATTS):	.0990					
CHIP N09:	13.256	13.114	12.834	13.144	13.144	15.445
POWER (WATTS):	.0992					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.967	10.012	09.997
TOP:	10.037	00.000	10.042

BACK PLANE TEMPERATURES :

T(55): 12.656  
 T(56): 12.961  
 T(57): 12.709  
 T(74): 13.131  
 T(75): 13.561  
 T(76): 13.671  
 T(77): 13.366

SOURCE VOLTAGE: 1.225

VOLTAGE TO THE HEATERS :

CHIP #1: .972  
 CHIP #2: 1.027  
 CHIP #3: 1.022  
 CHIP #4: 1.024  
 CHIP #5: .968  
 CHIP #6: 1.022  
 CHIP #7: 1.023  
 CHIP #8: 1.023  
 CHIP #9: 1.023

TABLE 18

**TEMPERATURE DATA FOR INPUT POWER 0.7 W  
CHAMBER WIDTH = 30 mm**

RESULTS ARE STORED IN FILE: 10170950

EXPERIMENT CARRIED OUT AT  
AMBIENT TEMP (CELSIUS) OF: 24.78  
BATH TEMP : 10 C-10 C

TEMPERATURE READINGS IN DEGREES CELSIUS						
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	21.48	21.22	21.08	21.31	20.01	24.28
POWER (WATTS):	.708					
CHIP NO2:	22.18	21.50	18.45	21.41	20.88	24.34
POWER (WATTS):	.712					
CHIP NO3:	22.65	21.48	00.00	21.56	21.98	24.44
POWER (WATTS):	.719					
CHIP NO4:	21.68	21.26	20.78	21.12	20.37	24.39
POWER (WATTS):	.715					
CHIP NO5:	21.93	21.19	21.53	21.74	21.48	24.42
POWER (WATTS):	.718					
CHIP NO6:	22.75	21.81	22.07	20.73	20.12	24.48
POWER (WATTS):	.721					
CHIP NO7:	21.14	20.83	21.34	20.95	19.34	24.44
POWER (WATTS):	.719					
CHIP NO8:	22.00	21.42	21.32	00.00	20.87	24.43
POWER (WATTS):	.718					
CHIP NO9:	22.65	20.64	18.15	22.02	21.83	24.42
POWER (WATTS):	.717					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.922	10.017	09.972
TOP:	09.977	00.000	10.060

BACK PLANE TEMPERATURES :

T(55): 15.191  
 T(56): 15.611  
 T(57): 14.265  
 T(74): 15.651  
 T(75): 16.079  
 T(76): 16.521  
 T(77): 15.350

SOURCE VOLTAGE: 3.288

VOLTAGE TO THE HEATERS :

CHIP #1: 2.610  
 CHIP #2: 2.756  
 CHIP #3: 2.743  
 CHIP #4: 2.747  
 CHIP #5: 2.597  
 CHIP #6: 2.741  
 CHIP #7: 2.743  
 CHIP #8: 2.744  
 CHIP #9: 2.745

TABLE 19

**TEMPERATURE DATA FOR INPUT POWER 1.1 W  
CHAMBER WIDTH = 30 mm**

RESULTS ARE STORED IN FILE: 10171720

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 25.94  
 BATH TEMP : 10 C-10 C

	TEMPERATURE READINGS IN DEGREES CELSIUS					
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	26.38	25.79	25.94	26.17	24.21	29.857
POWER (WATTS):	1.092					
CHIP N02:	27.34	26.00	22.01	26.17	25.62	29.96
POWER (WATTS):	1.099					
CHIP N03:	27.67	25.73	00.00	26.08	26.69	30.11
POWER (WATTS):	1.1093					
CHIP N04:	26.74	26.07	25.51	26.00	24.85	30.02
POWER (WATTS):	1.103					
CHIP N05:	29.78	25.86	26.40	26.71	26.35	30.08
POWER (WATTS):	1.107					
CHIP N06:	27.51	25.54	26.74	25.65	24.17	30.16
POWER (WATTS):	1.113					
CHIP N07:	25.80	25.40	26.18	25.63	22.98	30.10
POWER (WATTS):	1.109					
CHIP N08:	27.06	25.80	26.15	00.00	25.29	30.11
POWER (WATTS):	1.109					
CHIP N09:	27.79	24.71	21.36	26.94	26.60	30.11
POWER (WATTS):	1.110					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.924	10.015	09.987
TOP:	10.010	00.000	10.068

BACK PLANE TEMPERATURES :

T(55): 16.88  
 T(56): 17.48  
 T(57): 15.70  
 T(74): 17.57  
 T(75): 18.00  
 T(76): 18.49  
 T(77): 17.08

SOURCE VOLTAGE: 4.085

- VOLTAGE TO THE HEATERS :

CHIP #1: 3.244  
 CHIP #2: 3.424  
 CHIP #3: 3.408  
 CHIP #4: 3.413  
 CHIP #5: 3.228  
 CHIP #6: 3.406  
 CHIP #7: 3.408  
 CHIP #8: 3.408  
 CHIP #9: 3.408

TABLE 20

**TEMPERATURE DATA FOR INPUT POWER 1.5 W  
CHAMBER WIDTH = 30 mm**

RESULTS ARE STORED IN FILE: 10181020

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 23.94  
 BATH TEMP : 10 C-10 C

	TEMPERATURE READINGS IN DEGREES CELSIUS					
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	33.07	32.50	32.62	32.72	29.91	35.55
POWER (WATTS):	1.484					
CHIP NO2:	34.32	32.62	27.17	32.75	31.80	35.68
POWER (WATTS):	1.493					
CHIP NO3:	34.63	32.10	00.00	32.62	33.39	35.89
POWER (WATTS):	1.5077					
CHIP NO4:	33.56	32.40	31.90	32.49	30.83	35.79
POWER (WATTS):	1.501					
CHIP NO5:	33.39	32.19	32.67	33.16	32.64	35.87
POWER (WATTS):	1.506					
CHIP NO6:	34.02	31.20	33.07	32.41	29.59	35.97
POWER (WATTS):	1.513					
CHIP NO7:	32.02	30.79	32.47	31.73	27.98	35.89
POWER (WATTS):	1.508					
CHIP NO8:	33.89	32.28	32.71	00.00	31.39	35.89
POWER (WATTS):	1.507					
CHIP NO9:	34.69	31.22	26.04	33.41	33.00	35.88
POWER (WATTS):	1.507					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.027	10.098	10.073
TOP:	10.108	00.000	10.126

## BACK PLANE TEMPERATURES :

T(55): 19.59  
 T(56): 20.25  
 T(57): 17.80  
 T(74): 21.09  
 T(75): 20.76  
 T(76): 21.47  
 T(77): 19.69

SOURCE VOLTAGE: 4.767

## VOLTAGE TO THE HEATERS :

CHIP #1: 3.787  
 CHIP #2: 3.997  
 CHIP #3: 3.979  
 CHIP #4: 3.983  
 CHIP #5: 3.767  
 CHIP #6: 3.975  
 CHIP #7: 3.979  
 CHIP #8: 3.979  
 CHIP #9: 3.979

THESE RESULTS ARE NOW STORED ON DISK 'FASTSCAN

FILE: 30MM10R

TABLE 21

**TEMPERATURE DATA FOR INPUT POWER 2.5 W**  
**CHAMBER WIDTH = 30 mm**

RESULTS ARE STORED IN FILE: 10182338

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 23.17  
 BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	42.47	41.80	41.39	42.04	37.20	49.73
POWER (WATTS):	2.461					
CHIP N02:	44.31	40.93	41.68	41.68	40.14	49.93
POWER (WATTS):	2.475					
CHIP N03:	44.77	41.10	00.00	41.43	42.66	50.28
POWER (WATTS):	2.4985					
CHIP N04:	42.78	40.79	40.47	41.00	38.73	50.08
POWER (WATTS):	2.485					
CHIP N05:	42.58	42.08	41.60	42.36	41.83	50.20
POWER (WATTS):	2.494					
CHIP N06:	42.77	38.65	41.30	41.37	35.79	50.41
POWER (WATTS):	2.507					
CHIP N07:	40.63	39.59	41.08	40.51	34.17	50.25
POWER (WATTS):	2.497					
CHIP N08:	42.02	39.95	40.79	00.00	37.88	50.27
POWER (WATTS):	2.498					
CHIP N09:	42.77	37.10	41.32	41.32	40.60	50.24
POWER (WATTS):	2.496					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.020	10.110	10.065
TOP:	09.748	00.000	10.015

BACK PLANE TEMPERATURES :

T(55): 21.28  
 T(56): 22.30  
 T(57): 19.47  
 T(74): 23.34  
 T(75): 22.77  
 T(76): 23.81  
 T(77): 21.70

SOURCE VOLTAGE: 6.142

VOLTAGE TO THE HEATERS :

CHIP #1: 4.881  
 CHIP #2: 5.152  
 CHIP #3: 5.128  
 CHIP #4: 5.135  
 CHIP #5: 4.859  
 CHIP #6: 5.124  
 CHIP #7: 5.129  
 CHIP #8: 5.129  
 CHIP #9: 5.129

TABLE 22

**TEMPERATURE DATA FOR INPUT POWER 3.0 W  
CHAMBER WIDTH = 30 mm**

RESULTS ARE STORED IN FILE: 10232224

EXPERIMENT CARRIED OUT AT  
AMBIENT TEMP (CELSIUS) OF: 22.83  
BATH TEMP : 10 C

	TEMPERATURE READINGS IN DEGREES CELSIUS					
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	50.66	49.62	49.07	49.97	43.61	57.87
POWER (WATTS):	3.022					
CHIP N02:	52.71	47.72	49.42	49.42	46.37	58.10
POWER (WATTS):	3.038					
CHIP N03:	52.51	48.65	00.00	47.22	49.87	58.53
POWER (WATTS):	3.0672					
CHIP N04:	51.15	47.96	48.59	48.79	46.00	58.30
POWER (WATTS):	3.051					
CHIP N05:	50.48	48.36	49.36	50.54	48.61	58.47
POWER (WATTS):	3.063					
CHIP N06:	51.67	42.15	48.38	47.63	46.09	58.70
POWER (WATTS):	3.079					
CHIP N07:	48.27	46.25	48.70	48.07	39.78	58.52
POWER (WATTS):	3.066					
CHIP N08:	49.10	45.58	48.05	00.00	44.02	58.53
POWER (WATTS):	3.067					
CHIP N09:	50.71	41.39	43.01	43.01	45.34	58.49
POWER (WATTS):	3.064					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.057	10.166	10.176
TOP:	10.073	00.000	10.163

BACK PLANE TEMPERATURES :

T(55): 24.75  
T(56): 26.51  
T(57): 22.64  
T(74): 28.00  
T(75): 26.95  
T(76): 28.63  
T(77): 25.41

SOURCE VOLTAGE: 6.807

VOLTAGE TO THE HEATERS :

CHIP #1: 5.411  
CHIP #2: 5.712  
CHIP #3: 5.685  
CHIP #4: 5.692  
CHIP #5: 5.385  
CHIP #6: 5.680  
CHIP #7: 5.685  
CHIP #8: 5.685  
CHIP #9: 5.686



TABLE 23

**REDUCED DATA FOR INPUT POWER 0.1 W  
CHAMBER WIDTH = 30 mm**

THE RAW Cmf DATA ARE FROM THE FILE: 10161810  
THE POWER SETTING PER CHIP WAS: 0.1 W  
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	QNET(W)	Tavg-Is	Nu1	Nu2	
1	.10	2.75	23.19	10.85	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 12.861				
	SINK TEMPERATURE: 10.104				
2	.10	2.82	22.77	10.66	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 12.925				
	SINK TEMPERATURE: 10.104				
3	.10	3.04	21.32	9.98	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 13.144				
	SINK TEMPERATURE: 10.104				
4	.10	2.63	24.48	11.46	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 12.734				
	SINK TEMPERATURE: 10.104				
5	.10	2.83	22.82	10.68	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 12.934				
	SINK TEMPERATURE: 10.104				
6	.10	2.68	24.11	11.28	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 12.788				
	SINK TEMPERATURE: 10.104				
7	.10	2.68	24.10	11.26	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 12.782				
	SINK TEMPERATURE: 10.104				
8	.10	2.99	21.58	10.10	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 13.089				
	SINK TEMPERATURE: 10.104				
9	.10	3.10	20.84	9.75	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 13.202				
	SINK TEMPERATURE: 10.104				

TABLE 24

**REDUCED DATA FOR INPUT POWER 0.7 W  
CHAMBER WIDTH = 30 mm**

THE RAW  $Emf$  DATA ARE FROM THE FILE: 10170950  
THE POWER SETTING PER CHIP WAS: 0.7 W  
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	.70	11.22	40.87	19.12
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.41
AVERAGE TEMPERATURE: 21.294				
SINK TEMPERATURE: 10.073				
2	.71	10.92	42.23	19.76
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.42
AVERAGE TEMPERATURE: 20.990				
SINK TEMPERATURE: 10.073				
3	.71	12.11	38.48	18.00
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.48
AVERAGE TEMPERATURE: 22.185				
SINK TEMPERATURE: 10.073				
4	.71	11.20	41.37	19.36
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.44
AVERAGE TEMPERATURE: 21.273				
SINK TEMPERATURE: 10.073				
5	.71	11.71	39.73	18.59
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.46
AVERAGE TEMPERATURE: 21.783				
SINK TEMPERATURE: 10.073				
6	.72	11.81	39.61	18.53
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.48
AVERAGE TEMPERATURE: 21.878				
SINK TEMPERATURE: 10.073				
7	.71	10.99	42.38	19.83
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.45
AVERAGE TEMPERATURE: 21.066				
SINK TEMPERATURE: 10.073				
8	.71	11.61	40.07	18.75
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.46
AVERAGE TEMPERATURE: 21.685				
SINK TEMPERATURE: 10.073				
9	.71	11.16	41.64	19.48
FLUX BASED RAYLEIGH NUMBER * E-9 IS:				2.44
AVERAGE TEMPERATURE: 21.235				
SINK TEMPERATURE: 10.073				

TABLE 25

REDUCED DATA FOR INPUT POWER 1.1 W  
CHAMBER WIDTH = 30 mm

THE RAW Emf DATA ARE FROM THE FILE: 10171720  
THE POWER SETTING PER CHIP WAS: 1.1 W  
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	ONET(N)	Tavg-Ts	Nu1	Nu2
1	1.08	16.00	44.33	20.74
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.93			
	AVERAGE TEMPERATURE: 26.089			
	SINK TEMPERATURE: 10.085			
2	1.09	15.48	46.12	21.58
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.94			
	AVERAGE TEMPERATURE: 25.562			
	SINK TEMPERATURE: 10.085			
3	1.10	16.83	42.84	20.04
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.03			
	AVERAGE TEMPERATURE: 26.917			
	SINK TEMPERATURE: 10.085			
4	1.09	16.05	44.67	20.90
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.98			
	AVERAGE TEMPERATURE: 26.136			
	SINK TEMPERATURE: 10.085			
5	1.10	17.57	40.98	19.17
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.06			
	AVERAGE TEMPERATURE: 27.657			
	SINK TEMPERATURE: 10.085			
6	1.10	16.42	44.03	20.60
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.03			
	AVERAGE TEMPERATURE: 26.509			
	SINK TEMPERATURE: 10.085			
7	1.10	15.60	46.18	21.60
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.98			
	AVERAGE TEMPERATURE: 25.688			
	SINK TEMPERATURE: 10.085			
8	1.10	16.43	43.88	20.53
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 4.02			
	AVERAGE TEMPERATURE: 26.519			
	SINK TEMPERATURE: 10.085			
9	1.10	15.63	46.12	21.58
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 3.98			
	AVERAGE TEMPERATURE: 25.717			
	SINK TEMPERATURE: 10.085			

TABLE 26

**REDUCED DATA FOR INPUT POWER 1.5 W**  
**CHAMBER WIDTH = 30 mm**

THE RAW  $Emf$  DATA ARE FROM THE FILE: 10211130  
 THE POWER SETTING PER CHIP WAS: 1.5 W  
 THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	QNET(W)	T <sub>avg</sub> -T <sub>s</sub>	Nu1	Nu2
1	1.52	22.39	44.65	20.89
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.94			
	AVERAGE TEMPERATURE: 32.569			
	SINK TEMPERATURE: 10.180			
2	1.53	21.80	46.10	21.57
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.94			
	AVERAGE TEMPERATURE: 31.978			
	SINK TEMPERATURE: 10.180			
3	1.54	24.07	42.22	19.75
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.15			
	AVERAGE TEMPERATURE: 34.252			
	SINK TEMPERATURE: 10.180			
4	1.54	22.27	45.37	21.23
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.00			
	AVERAGE TEMPERATURE: 32.450			
	SINK TEMPERATURE: 10.180			
5	1.54	23.39	43.35	20.28
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.09			
	AVERAGE TEMPERATURE: 33.574			
	SINK TEMPERATURE: 10.180			
6	1.55	22.61	45.06	21.08
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.07			
	AVERAGE TEMPERATURE: 32.788			
	SINK TEMPERATURE: 10.180			
7	1.54	21.66	46.86	21.92 <sup>†</sup>
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.99			
	AVERAGE TEMPERATURE: 31.837			
	SINK TEMPERATURE: 10.180			
8	1.54	22.30	45.54	21.30
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.03			
	AVERAGE TEMPERATURE: 32.482			
	SINK TEMPERATURE: 10.180			
9	1.54	20.60	49.26	23.05
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.92			
	AVERAGE TEMPERATURE: 30.782			
	SINK TEMPERATURE: 10.180			

TABLE 27

**REDUCED DATA FOR INPUT POWER 2.5 W  
CHAMBER WIDTH = 30 mm**

THE RAW Emf DATA ARE FROM THE FILE: 10182338  
THE POWER SETTING PER CHIP WAS: 2.5 W  
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	ONET(W)	T <sub>avg</sub> -T <sub>s</sub>	Nu1	Nu2
1	2.44	31.61	51.08	23.90
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.54			
	AVERAGE TEMPERATURE: 41.698			
	SINK TEMPERATURE: 10.087			
2	2.45	30.24	53.65	25.10
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.44			
	AVERAGE TEMPERATURE: 40.331			
	SINK TEMPERATURE: 10.087			
3	2.48	33.03	49.69	23.25
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.86			
	AVERAGE TEMPERATURE: 43.113			
	SINK TEMPERATURE: 10.087			
4	2.46	31.27	52.14	24.39
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.60			
	AVERAGE TEMPERATURE: 41.356			
	SINK TEMPERATURE: 10.087			
5	2.47	32.19	50.86	23.79
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.74			
	AVERAGE TEMPERATURE: 42.277			
	SINK TEMPERATURE: 10.087			
6	2.49	31.14	52.84	24.72
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.68			
	AVERAGE TEMPERATURE: 41.225			
	SINK TEMPERATURE: 10.087			
7	2.48	30.10	54.39	25.44
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.52			
	AVERAGE TEMPERATURE: 40.189			
	SINK TEMPERATURE: 10.087			
8	2.48	30.94	52.97	24.78
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.62			
	AVERAGE TEMPERATURE: 41.023			
	SINK TEMPERATURE: 10.087			
9	2.48	28.94	56.51	26.44
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.39			
	AVERAGE TEMPERATURE: 39.028			
	SINK TEMPERATURE: 10.087			

TABLE 28

**REDUCED DATA FOR INPUT POWER 3.0 W  
CHAMBER WIDTH = 30 mm**

THE RAW Emf DATA ARE FROM THE FILE: 10191310  
THE POWER SETTING PER CHIP WAS: 3.0 W  
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	2.96	38.29	51.36	24.03
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.73			
	AVERAGE TEMPERATURE: 48.440			
	SINK TEMPERATURE: 10.154			
2	2.98	36.50	54.14	25.33
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.56			
	AVERAGE TEMPERATURE: 46.657			
	SINK TEMPERATURE: 10.154			
3	3.01	38.80	51.50	24.10
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 14.03			
	AVERAGE TEMPERATURE: 48.959			
	SINK TEMPERATURE: 10.154			
4	2.99	38.03	52.27	24.46
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.85			
	AVERAGE TEMPERATURE: 48.185			
	SINK TEMPERATURE: 10.154			
5	3.00	38.62	51.66	24.17
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.98			
	AVERAGE TEMPERATURE: 48.777			
	SINK TEMPERATURE: 10.154			
6	3.02	36.60	54.74	25.61
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.76			
	AVERAGE TEMPERATURE: 46.755			
	SINK TEMPERATURE: 10.154			
7	3.01	36.49	54.71	25.60 <sup>f</sup>
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.69			
	AVERAGE TEMPERATURE: 46.642			
	SINK TEMPERATURE: 10.154			
8	3.01	36.62	54.55	25.52
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.72			
	AVERAGE TEMPERATURE: 46.771			
	SINK TEMPERATURE: 10.154			
9	3.01	33.27	59.88	28.01
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 13.23			
	AVERAGE TEMPERATURE: 43.421			
	SINK TEMPERATURE: 10.154			

TABLE 29

**TEMPERATURE DATA FOR INPUT POWER 0.1 W**  
**CHAMBER WIDTH = 9 mm**

RESULTS ARE STORED IN FILE: 11050029

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 22.78  
 BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	14.34	14.25	14.16	14.24	14.08	14.40
POWER (WATTS):	.097					
CHIP NO2:	14.48	14.33	14.32	14.32	14.22	14.54
POWER (WATTS):	.098					
CHIP NO3:	14.58	14.53	14.49	14.48	14.54	14.64
POWER (WATTS):	.0989					
CHIP NO4:	14.39	14.25	14.10	14.12	14.02	14.45
POWER (WATTS):	.099					
CHIP NO5:	14.43	15.89	14.33	14.37	14.26	14.49
POWER (WATTS):	.099					
CHIP NO6:	14.65	14.37	00.00	14.24	14.58	14.71
POWER (WATTS):	.099					
CHIP NO7:	14.13	14.14	14.19	14.17	14.08	14.19
POWER (WATTS):	.099					
CHIP NO8:	14.59	14.41	14.42	00.00	14.24	14.65
POWER (WATTS):	.099					
CHIP NO9:	14.71	14.28	16.01	16.01	14.45	14.77
POWER (WATTS):	.099					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.914	09.967	09.965
TOP:	10.011	00.000	10.392

BACK PLANE TEMPERATURES :

T(55): 12.97  
 T(56): 13.12  
 T(74): 13.52  
 T(75): 13.83  
 T(76): 13.99  
 T(77): 13.25

SOURCE VOLTAGE: 1.219

VOLTAGE TO THE HEATERS :

CHIP #1: .967  
 CHIP #2: 1.021  
 CHIP #3: 1.016  
 CHIP #4: 1.017  
 CHIP #5: .962  
 CHIP #6: 1.015  
 CHIP #7: 1.015  
 CHIP #8: 1.015  
 CHIP #9: 1.016

TABLE 30

**TEMPERATURE DATA FOR INPUT POWER 0.7 W**  
**CHAMBER WIDTH = 9 mm**

RESULTS ARE STORED IN FILE: 11062057

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 20.61

BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	23.48	23.27	22.85	23.21	21.49	23.88
POWER (WATTS):	.696					
CHIP NO2:	24.85	23.75	23.74	23.74	23.07	25.26
POWER (WATTS):	.701					
CHIP NO3:	24.78	24.57	24.32	23.70	24.51	25.19
POWER (WATTS):	.7050					
CHIP NO4:	23.92	22.97	22.82	22.78	21.97	24.32
POWER (WATTS):	.703					
CHIP NO5:	24.77	23.82	24.12	24.42	23.69	25.17
POWER (WATTS):	.705					
CHIP NO6:	25.92	23.76	00.00	23.15	25.35	26.33
POWER (WATTS):	.709					
CHIP NO7:	23.12	22.57	23.13	22.84	21.02	23.53
POWER (WATTS):	.707					
CHIP NO8:	24.84	23.90	23.94	00.00	22.83	25.25
POWER (WATTS):	.707					
CHIP NO9:	25.78	22.75	19.26	23.34	24.30	26.19
POWER (WATTS):	.706					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.972	10.070	10.088
TOP:	10.047	00.000	10.137

BACK PLANE TEMPERATURES :

T(55): 15.17  
 T(56): 15.45  
 T(74): 15.92  
 T(75): 15.99  
 T(76): 16.29  
 T(77): 15.68

SOURCE VOLTAGE: 3.259

VOLTAGE TO THE HEATERS :

CHIP #1: 2.587  
 CHIP #2: 2.731  
 CHIP #3: 2.720  
 CHIP #4: 2.722  
 CHIP #5: 2.575  
 CHIP #6: 2.717  
 CHIP #7: 2.718  
 CHIP #8: 2.718  
 CHIP #9: 2.720



TABLE 31

**TEMPERATURE DATA FOR INPUT POWER 1.1 W  
CHAMBER WIDTH = 9 mm**

RESULTS ARE STORED IN FILE: 11022255

EXPERIMENT CARRIED OUT AT  
AMBIENT TEMP (CELSIUS) OF: 21.11  
BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS						
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	28.92	28.61	28.26	28.57	25.77	29.87
POWER (WATTS):	1.093					
CHIP NO2:	31.27	29.86	29.60	29.60	28.52	29.97
POWER (WATTS):	1.100					
CHIP NO3:	30.49	30.42	30.02	28.65	30.37	30.08
POWER (WATTS):	1.1071					
CHIP NO4:	29.63	28.45	28.11	27.89	26.78	30.04
POWER (WATTS):	1.104					
CHIP NO5:	31.16	29.79	30.20	30.63	29.54	30.08
POWER (WATTS):	1.107					
CHIP NO6:	31.91	28.89	00.00	28.72	31.17	30.18
POWER (WATTS):	1.114					
CHIP NO7:	28.48	27.51	28.46	28.34	25.07	30.15
POWER (WATTS):	1.112					
CHIP NO8:	31.20	30.08	30.00	00.00	28.01	30.14
POWER (WATTS):	1.111					
CHIP NO9:	32.68	28.26	31.03	31.03	30.57	30.11
POWER (WATTS):	1.110					

HEAT EXCHANGERS TEMPERATURES:			
	RIGHT	CENTER	LEFT
BOTTOM:	09.839	10.128	10.241
TOP:	09.863	00.000	09.952

BACK PLANE TEMPERATURES :

T(55): 17.38  
T(56): 17.58  
T(74): 18.00  
T(75): 18.02  
T(76): 18.41  
T(77): 17.63

SOURCE VOLTAGE: 4.086

VOLTAGE TO THE HEATERS :

CHIP #1: 3.244  
CHIP #2: 3.425  
CHIP #3: 3.411  
CHIP #4: 3.413  
CHIP #5: 3.229  
CHIP #6: 3.406  
CHIP #7: 3.407  
CHIP #8: 3.408  
CHIP #9: 3.409

TABLE 32

**TEMPERATURE DATA FOR INPUT POWER 1.5 W**  
**CHAMBER WIDTH = 9 mm**

RESULTS ARE STORED IN FILE: 11091225

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 21.83  
 BATH TEMP : 10 C

	TEMPERATURE READINGS IN DEGREES CELSIUS					
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	36.71	36.38	35.78	36.25	32.76	37.56
POWER (WATTS):	1.489					
CHIP NO2:	38.97	36.79	37.06	37.06	35.88	39.83
POWER (WATTS):	1.497					
CHIP NO3:	38.33	37.92	37.67	34.98	37.83	39.20
POWER (WATTS):	1.5093					
CHIP NO4:	37.06	35.37	35.16	34.59	33.41	37.92
POWER (WATTS):	1.504					
CHIP NO5:	38.29	36.57	37.19	37.75	36.20	39.16
POWER (WATTS):	1.508					
CHIP NO6:	39.40	35.38	00.00	34.97	38.23	40.27
POWER (WATTS):	1.516					
CHIP NO7:	34.94	33.67	35.04	34.46	30.18	35.81
POWER (WATTS):	1.512					
CHIP NO8:	38.18	35.83	36.98	00.00	34.50	39.05
POWER (WATTS):	1.512					
CHIP NO9:	39.71	34.80	28.60	36.52	36.09	40.58
POWER (WATTS):	1.511					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.828	09.977	10.040
TOP:	10.007	00.000	10.295

BACK PLANE TEMPERATURES :

T(55): 20.82  
 T(56): 21.73  
 T(74): 22.48  
 T(75): 22.33  
 T(76): 22.64  
 T(77): 21.31

SOURCE VOLTAGE: 4.771

VOLTAGE TO THE HEATERS :

CHIP #1: 3.789  
 CHIP #2: 4.000  
 CHIP #3: 3.983  
 CHIP #4: 3.987  
 CHIP #5: 3.772  
 CHIP #6: 3.979  
 CHIP #7: 3.981  
 CHIP #8: 3.982  
 CHIP #9: 3.983

TABLE 33

**TEMPERATURE DATA FOR INPUT POWER 2.5 W**  
**CHAMBER WIDTH = 9 mm**

RESULTS ARE STORED IN FILE: 11082020

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 21.28  
 BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	46.62	45.93	45.41	46.08	40.22	48.05
POWER (WATTS):	2.504					
CHIP NO2:	50.04	46.15	47.23	47.23	43.85	51.48
POWER (WATTS):	2.520					
CHIP NO3:	48.91	48.75	48.04	45.63	48.30	50.37
POWER (WATTS):	2.5388					
CHIP NO4:	47.00	43.52	44.22	42.84	41.35	48.45
POWER (WATTS):	2.531					
CHIP NO5:	48.77	46.61	47.23	48.29	45.89	50.23
POWER (WATTS):	2.538					
CHIP NO6:	49.99	44.34	00.00	44.08	48.13	51.45
POWER (WATTS):	2.552					
CHIP NO7:	43.36	41.13	43.65	42.69	35.63	44.82
POWER (WATTS):	2.544					
CHIP NO8:	48.86	45.42	47.09	00.00	43.17	50.32
POWER (WATTS):	2.544					
CHIP NO9:	49.89	42.54	34.29	45.52	45.93	51.35
POWER (WATTS):	2.541					

HEAT EXCHANGERS TEMPERATURES: RIGHT CENTER LEFT  
 BOTTOM: 09.859 10.037 10.110  
 TOP: 09.803 00.000 10.073

BACK PLANE TEMPERATURES :

T(55): 22.95  
 T(56): 24.01  
 T(74): 24.80  
 T(75): 24.59  
 T(76): 24.97  
 T(77): 23.67

SOURCE VOLTAGE: 6.193

VOLTAGE TO THE HEATERS :

CHIP #1: 4.921  
 CHIP #2: 5.193  
 CHIP #3: 5.172  
 CHIP #4: 5.176  
 CHIP #5: 4.897  
 CHIP #6: 5.165  
 CHIP #7: 5.169  
 CHIP #8: 5.169  
 CHIP #9: 5.171

TABLE 34

**TEMPERATURE DATA FOR INPUT POWER 3.0 W**  
**CHAMBER WIDTH = 9 mm**

RESULTS ARE STORED IN FILE: 11072058

EXPERIMENT CARRIED OUT AT  
 AMBIENT TEMP (CELSIUS) OF: 21.00  
 BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS							
	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK	
CHIP N01:	55.97	54.46	55.08	55.59	45.61	57.66	
POWER (WATTS):	2.938						
CHIP N02:	61.12	57.34	58.19	58.19	54.57	62.82	
POWER (WATTS):	2.957						
CHIP N03:	58.47	58.54	57.89	55.35	58.30	60.18	
POWER (WATTS):	2.9774						
CHIP N04:	57.35	53.88	54.52	54.33	49.46	59.05	
POWER (WATTS):	2.969						
CHIP N05:	58.98	57.68	58.44	59.12	56.79	60.69	
POWER (WATTS):	2.978						
CHIP N06:	61.17	55.49	00.00	55.89	59.33	62.89	
POWER (WATTS):	2.993						
CHIP N07:	52.97	51.59	53.54	53.26	43.41	54.68	
POWER (WATTS):	2.984						
CHIP N08:	60.57	57.20	59.10	00.00	54.97	62.28	
POWER (WATTS):	2.985						
CHIP N09:	60.45	53.52	46.33	56.95	56.66	62.17	
POWER (WATTS):	2.984						

HEAT EXCHANGERS TEMPERATURES:			
	RIGHT	CENTER	LEFT
BOTTOM:	09.783	10.022	10.176
TOP:	09.816	00.000	10.063

BACK PLANE TEMPERATURES :

T(55): 32.35  
 T(56): 34.45  
 T(74): 35.59  
 T(75): 35.08  
 T(76): 35.20  
 T(77): 33.52

SOURCE VOLTAGE: 6.715

VOLTAGE TO THE HEATERS :

CHIP #1: 5.339  
 CHIP #2: 5.633  
 CHIP #3: 5.611  
 CHIP #4: 5.615  
 CHIP #5: 5.314  
 CHIP #6: 5.603  
 CHIP #7: 5.608  
 CHIP #8: 5.607  
 CHIP #9: 5.608

TABLE 35

**REDUCED DATA FOR INPUT POWER 0.1 W**  
**CHAMBER WIDTH = 9 mm**

THE RAW Emf DATA ARE FROM THE FILE: 11050029  
 THE POWER SETTING PER CHIP WAS: 0.1 W  
 THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	ONET(N)	T <sub>avg</sub> -T <sub>s</sub>	Nu1	Nu2	
1	.10	4.10	15.19	7.11	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.30
	AVERAGE TEMPERATURE: 14.242				
	SINK TEMPERATURE: 10.139				
2	.10	4.08	15.38	7.19	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.221				
	SINK TEMPERATURE: 10.139				
3	.10	4.39	14.43	6.75	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.525				
	SINK TEMPERATURE: 10.139				
4	.10	4.07	15.54	7.27	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.208				
	SINK TEMPERATURE: 10.139				
5	.10	4.36	14.52	6.80	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.497				
	SINK TEMPERATURE: 10.139				
6	.10	4.33	14.70	6.88	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.473				
	SINK TEMPERATURE: 10.139				
7	.10	4.01	15.86	7.42	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.153				
	SINK TEMPERATURE: 10.139				
8	.10	4.33	14.67	6.86	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.471				
	SINK TEMPERATURE: 10.139				
9	.10	4.52	14.00	6.55	
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:				.31
	AVERAGE TEMPERATURE: 14.660				
	SINK TEMPERATURE: 10.139				

TABLE 36

**REDUCED DATA FOR INPUT POWER 0.7 W**  
**CHAMBER WIDTH = 9 mm**

THE RAW Emf DATA ARE FROM THE FILE: 11062057  
 THE POWER SETTING PER CHIP WAS: 0.7 W  
 THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	T <sub>avg</sub> -T <sub>s</sub>	Nu1	Nu2
1	.68	13.03	34.38	16.08
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.41			
	AVERAGE TEMPERATURE: 23.174			
	SINK TEMPERATURE: 10.145			
2	.69	13.11	34.42	16.10
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.43			
	AVERAGE TEMPERATURE: 23.251			
	SINK TEMPERATURE: 10.145			
3	.69	14.31	31.75	14.86
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.48			
	AVERAGE TEMPERATURE: 24.456			
	SINK TEMPERATURE: 10.145			
4	.69	13.07	34.63	16.20
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.44			
	AVERAGE TEMPERATURE: 23.219			
	SINK TEMPERATURE: 10.145			
5	.69	14.31	31.75	14.86
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.48			
	AVERAGE TEMPERATURE: 24.451			
	SINK TEMPERATURE: 10.145			
6	.70	14.65	31.20	14.60
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.50			
	AVERAGE TEMPERATURE: 24.794			
	SINK TEMPERATURE: 10.145			
7	.70	12.79	35.62	16.66
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.44			
	AVERAGE TEMPERATURE: 22.933			
	SINK TEMPERATURE: 10.145			
8	.70	14.17	32.16	15.04
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.48			
	AVERAGE TEMPERATURE: 24.313			
	SINK TEMPERATURE: 10.145			
9	.69	13.12	34.64	16.21
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 2.45			
	AVERAGE TEMPERATURE: 23.266			
	SINK TEMPERATURE: 10.145			

TABLE 37

REDUCED DATA FOR INPUT POWER 1.1 W  
CHAMBER WIDTH = 9 mm

THE RAW Emf DATA ARE FROM THE FILE: 11022255  
THE POWER SETTING PER CHIP WAS: 1.1 W  
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	1.08	18.18	38.87	18.19
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.02
	AVERAGE TEMPERATURE: 28.377			
	SINK TEMPERATURE: 10.193			
2	1.08	18.63	38.19	17.87
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.07
	AVERAGE TEMPERATURE: 28.825			
	SINK TEMPERATURE: 10.193			
3	1.09	19.71	36.38	17.02
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.14
	AVERAGE TEMPERATURE: 29.898			
	SINK TEMPERATURE: 10.193			
4	1.09	18.29	39.06	18.28
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.07
	AVERAGE TEMPERATURE: 28.480			
	SINK TEMPERATURE: 10.193			
5	1.09	20.35	35.26	16.49
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.17
	AVERAGE TEMPERATURE: 30.538			
	SINK TEMPERATURE: 10.193			
6	1.10	20.24	35.66	16.68
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.19
	AVERAGE TEMPERATURE: 30.429			
	SINK TEMPERATURE: 10.193			
7	1.10	17.88	40.23	18.82
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.08
	AVERAGE TEMPERATURE: 28.076			
	SINK TEMPERATURE: 10.193			
8	1.10	20.13	35.76	16.73
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.18
	AVERAGE TEMPERATURE: 30.321			
	SINK TEMPERATURE: 10.193			
9	1.09	19.19	37.43	17.51
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			4.13
	AVERAGE TEMPERATURE: 29.382			
	SINK TEMPERATURE: 10.193			

TABLE 38

**REDUCED DATA FOR INPUT POWER 1.5 W**  
**CHAMBER WIDTH = 9 mm**

THE RAW Emf DATA ARE FROM THE FILE: 11091225  
 THE POWER SETTING PER CHIP WAS: 1.5 W  
 THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	$T_{avg}-T_s$	Nu1	Nu2
1	1.47	25.92	37.30	17.45
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			5.96
	AVERAGE TEMPERATURE: 36.108			
	SINK TEMPERATURE: 10.186			
2	1.47	25.87	37.60	17.59
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			6.00
	AVERAGE TEMPERATURE: 36.053			
	SINK TEMPERATURE: 10.186			
3	1.49	27.17	36.12	16.90
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			6.13
	AVERAGE TEMPERATURE: 37.353			
	SINK TEMPERATURE: 10.186			
4	1.48	25.44	38.39	17.96
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			5.99
	AVERAGE TEMPERATURE: 35.625			
	SINK TEMPERATURE: 10.186			
5	1.49	27.48	35.69	16.70
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			6.15
	AVERAGE TEMPERATURE: 37.664			
	SINK TEMPERATURE: 10.186			
6	1.49	27.26	36.16	16.92
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			6.17
	AVERAGE TEMPERATURE: 37.450			
	SINK TEMPERATURE: 10.186			
7	1.49	24.25	40.46	18.93
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			5.95
	AVERAGE TEMPERATURE: 34.440			
	SINK TEMPERATURE: 10.186			
8	1.49	27.02	36.36	17.01
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			6.13
	AVERAGE TEMPERATURE: 37.211			
	SINK TEMPERATURE: 10.186			
9	1.49	25.41	38.61	18.07
	FLUX BASED RAYLEIGH NUMBER * E-9 IS:			6.02
	AVERAGE TEMPERATURE: 35.592			
	SINK TEMPERATURE: 10.186			



TABLE 39

REDUCED DATA FOR INPUT POWER 2.5 W  
CHAMBER WIDTH = 9 mm

THE RAW Emf DATA ARE FROM THE FILE: 11082020  
THE POWER SETTING PER CHIP WAS: 2.5 W  
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	2.47	35.42	46.27	21.65
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.15			
	AVERAGE TEMPERATURE: 45.692			
	SINK TEMPERATURE: 10.271			
2	2.49	35.23	46.82	21.90
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.20			
	AVERAGE TEMPERATURE: 45.503			
	SINK TEMPERATURE: 10.271			
3	2.50	37.64	44.23	20.69
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.58			
	AVERAGE TEMPERATURE: 47.908			
	SINK TEMPERATURE: 10.271			
4	2.50	34.33	48.22	22.56
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.14			
	AVERAGE TEMPERATURE: 44.605			
	SINK TEMPERATURE: 10.271			
5	2.50	37.68	44.17	20.66
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.58			
	AVERAGE TEMPERATURE: 47.946			
	SINK TEMPERATURE: 10.271			
6	2.52	37.02	45.18	21.14
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.56			
	AVERAGE TEMPERATURE: 47.287			
	SINK TEMPERATURE: 10.271			
7	2.51	32.27	51.53	24.11
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.96			
	AVERAGE TEMPERATURE: 42.536			
	SINK TEMPERATURE: 10.271			
8	2.51	37.08	44.97	21.04
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.53			
	AVERAGE TEMPERATURE: 47.355			
	SINK TEMPERATURE: 10.271			
9	2.51	33.79	49.19	23.01
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 11.12			
	AVERAGE TEMPERATURE: 44.057			
	SINK TEMPERATURE: 10.271			

TABLE 40

**REDUCED DATA FOR INPUT POWER 3.0 W**  
**CHAMBER WIDTH = 9 mm**

THE RAW Emf DATA ARE FROM THE FILE: 11072058  
 THE POWER SETTING PER CHIP WAS: 3.0 W  
 THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	2.90	44.40	43.64	20.42
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 14.41			
	AVERAGE TEMPERATURE: 54.762			
	SINK TEMPERATURE: 10.362			
2	2.92	46.34	42.14	19.72
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 14.79			
	AVERAGE TEMPERATURE: 56.697			
	SINK TEMPERATURE: 10.362			
3	2.94	47.28	41.61	19.47
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 15.04			
	AVERAGE TEMPERATURE: 57.639			
	SINK TEMPERATURE: 10.362			
4	2.93	44.68	43.84	20.51
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 14.61			
	AVERAGE TEMPERATURE: 55.040			
	SINK TEMPERATURE: 10.362			
5	2.94	48.33	40.74	19.06
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 15.20			
	AVERAGE TEMPERATURE: 58.691			
	SINK TEMPERATURE: 10.362			
6	2.96	48.31	40.97	19.17
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 15.28			
	AVERAGE TEMPERATURE: 58.676			
	SINK TEMPERATURE: 10.362			
7	2.95	42.01	46.78	21.89
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 14.29			
	AVERAGE TEMPERATURE: 52.372			
	SINK TEMPERATURE: 10.362			
8	2.95	48.82	40.44	18.92
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 15.31			
	AVERAGE TEMPERATURE: 59.183			
	SINK TEMPERATURE: 10.362			
9	2.95	44.89	43.86	20.52
	FLUX BASED RAYLEIGH NUMBER * E-9 IS: 14.71			
	AVERAGE TEMPERATURE: 55.253			
	SINK TEMPERATURE: 10.362			

## APPENDIX D

### SOFTWARE LISTING

```

1  ! *****
10 ! PROGRAM CalcDiel *
20 ! *****
21 !
23 ! EDITED BY LT E. TORRES, FROM ORIGINALS OF
30 ! PAMUK [REF.12] AND BENEDICT [REF. 13]
31 !
40 ! *****
50 ! THIS PROGRAM ANALYSES THE DATA READ FROM *
60 ! A DATA FILE DESIGNATED BY THE OPERATOR,IT*
70 ! REDUCES THE DATA TO CALCULATIONS OF NET *
80 ! POWER, PAYLEIGH NUMBER AND NUSSELT NUMBER.*
90 ! *****
91 !
93 ! VARIABLES USED ARE :
94 ! Emf : VOLTAGE FROM THE THERMOCOUPLES.
95 ! POWER : POWER DISSIPATED BY THE HEATERS.
96 ! T(I) : TEMPERATURE CONVERTED FROM THERMOCOUPLES VOLTAGE.
97 !
98 ! TAVG : IS THE AVERAGE TEMPERATURE OF THE
99 ! CHIP. IT IS OBTAINED MULTIPLYING
100 ! THE TEMPERATURE FOUND IN EACH FACE
101 ! BY THE AREA AND DIVIDING BY THE TOTAL AREA.
102 !
103 ! Ts : CHIP BACK SURFACE TEMPERATURE.
104 ! Tfilm : FILM TEMPERATURE OF THE FC-75.
105 ! QNET : ELECTRIC POWER MINUS CONDUCTION LOSSES.
106 ! TSINK : AVERAGE OF THE 6 THERMOCOUPLES IN
107 ! THE UPPER AND LOWER HEAT-EXCHANGERS.
108 !
109 ! NU1 : VERTICAL LENGTH BASED NUSSELT NUMBER.
110 ! NU2 : AREA-PERIMETER BASED NUSSELT NUMBER.
111 ! OTHER VARIABLES ARE SELF EXPLANATORIES.
112 ! *****
113 !
114 !
115 COM /Co/ D(7)
116 !
117 DIM Emf(76),Power(9),T(76),Tavg(9),Ts(9)
118 DIM Tfilm(9),Qnet(9),H(9),k(9),Rho(9),Cp(9)
119 DIM N(9),Nu(9),Ra(9),Delt(9),Alta(9),Pr(9)
120 DIM Gr(9),Beta(9),Dpow(9),Dts(9),Rp(8)
121 !
122 ! CORRELATION FACTORS TO CONVERT Emf TO DEGREES CELSIUS.
123 DATA 0.10086091,25727.9,-767345.8,78025596.
124 DATA -3247486589.6,38E11,-2.66E13,3.34E14
125 DATA 2.50,2.06,2.08,2.08,2.50,2.08,2.08,2.08,2.08
126 !
127 READ D(1)
128 READ Rp(1)
129 !
130 PRINTER IS 701
131 BEEP
132 BEEP
133 !
134 INPUT "ENTER THE NAME OF THE FILE CONTAINING DATA",Oldfiles
135 !
136 PRINT USING "10X, ""THE RAW Emf DATA ARE FROM THE FILE: """,10A":Oldfiles
137 !
138 INPUT "ENTER THE POWER SETTING ",Powers
139 !

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```

340 PRINT USING "9X.1" THE POWER SETTING PER CHIP WAS: " ",10A":Power5
341 !
343 PRINT USING "10X.1"THE DISTANCE TO THE FRONT WALL WAS 9 MM ""
344 !
350 PRINT
370 !
380 BEEP
390 BEEP
400 ASSIGN @File TO Oldfile$
401 ENTER @File:Emf(+)
410 !
420 !+++++++
430 ! CONVERT Emf TO DEGREES CELSIUS *
431 !+++++++
432 !
440 FOR I=0 TO 60
450 Sum=0
460 FOR J=0 TO 7
470 Sum=Sum+D(J)*Emf(I)*J
480 NEXT J
490 T(I)=Sum
500 NEXT I
502 FOR I=71 TO 76
503 Sum=0
504 FOR J=0 TO 7
506 Sum=Sum+D(J)*Emf(I)*J
508 NEXT J
509 T(I)=Sum
510 NEXT I
511 !
513 !+++++++
520 ! CONVERT Emf TO POWER *
521 !+++++++
522 !
530 J=1
540 Volt=Emf(61)
550 FOR I=62 TO 70
560 Power(J)=Emf(I)*(Volt-Emf(I))/Rd*I-62)
580 J=J+1
590 NEXT I
591 !
600 !+++++++
610 ! AREA OF THE BLOCK FACES *
611 !+++++++
612 !
620 Acen=1.92E-4
630 Alef=1.44E-4
640 Arig=1.44E-4
650 Atop=4.3E-5
660 Abot=4.3E-5
670 Ato=5.76E-4
671 !
680 !+++++++
690 !CALCULATE THE AVERAGE TEMPERATURES OF THE BLOCK FACES *
691 !IF A THERMOCOUPLE IS FOUND OPENED,IT SHOULD BE TAKEN OFF.*
700 !+++++++
701 !
710 Tavg(1)=(T(0)*Acen+T(1)*Atop+T(2)*Arig+T(3)*Alef+T(4)*Abot)/Atot
720 Tavg(2)=(T(6)*Acen+T(7)*Atop+T(8)*Arig+T(9)*Alef+T(10)*Abot)/Atot

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740 Tavg(4)=(T(18)*Acen+T(19)*Atop+T(20)*Arig+T(21)*Alef+T(22)*Abot)/Atot
750 Tavg(5)=(T(24)*Acen+T(25)*Atop+T(26)*Arig+T(27)*Alef+T(28)*Abot)/Atot
760 Tavg(6)=(T(30)*Acen+T(31)*Atop+T(33)*Alef+T(34)*Abot)/(Atot-Alef)
770 Tavg(7)=(T(36)*Acen+T(37)*Atop+T(38)*Arig+T(39)*Alef+T(40)*Abot)/Atot
780 Tavg(8)=(T(42)*Acen+T(43)*Atop+T(44)*Arig+T(46)*Abot)/(Atot-Alef)
790 Tavg(9)=(T(48)*Acen+T(49)*Atop+T(50)*Arig+T(51)*Alef+T(52)*Abot)/Atot
800 !*****
850 ! RESISTANCE OF PLEXIGLASS, FOUND WITH A CONDUCTIVITY OF *
852 ! 0.195 W/m.K AND A LENGTH OF 19.5 MM.
853 !
860 Rc=520.83
880 !
881 !*****
890 ! CHIP BACK SURFACE TEMPERATURES *
891 !*****
900 Ts(1)=T(5)
910 Ts(2)=T(11)
920 Ts(3)=T(17)
930 Ts(4)=T(23)
940 Ts(5)=T(29)
950 Ts(6)=T(35)
960 Ts(7)=T(41)
970 Ts(8)=T(47)
980 Ts(9)=T(53)
990 Tssum=0
1000 FOR J=1 TO 9
1010 Tssum=Tssum+Ts(J)
1020 NEXT J
1030 !
1040 Tsave=Tssum/9
1041 !
1050 !*****
1060 ! CONDUCTION LOSS CALCULATION. *
1061 !*****
1062 !
1070 Qloss3=(T(17)-T(75))/Rc
1080 Qloss5=(T(29)-T(55))/Rc
1090 Qloss7=(T(41)-T(54))/Rc
1100 Qloss=(Qloss3+Qloss5+Qloss7)/3
1110 !
1120 !*****
1130 ! AVERAGE SINK TEMPERATURE CALCULATION *
1131 !*****
1132 !
1140 Tsink=(T(57)+T(58)+T(59)+T(60)+T(71)+T(72))/6
1150 !
1152 ! TWO CHARACTERISTIC LENGTHS, WILL BE USED TO CALCULATE NUSSELT NUMBERS :
1153 ! L1 BASED IN THE VERTICAL DIMENSION OF THE CHIP (24,MM)
1154 ! AND L2 BASED IN THE SUMATION OF THE AREAS DIVIDED BY THE PERIMETER.
1155 !
1160 L1=2.40E-2
1161 L2=(2.*16.*24./60.)+2.*(8.*6./28.)+8.*(24./54.)+.001
1170 !*****
1171 !
1173 !*****
1174 ! TO PRINT THE OUTPUT HEADINGS. *
1175 !*****
1176 !
1180 PRINT USING "9X," "CHIP QNET(W) Tavg-Ts Nu1 Nu2 " ",10A"
1200 PRINT
1210 !*****

```

```

1220 ! CALCULATION OF NET POWER, Nu AND Ra. *
1230 !*****
1231 !
1240 FOR J=1 TO 9
1250 !
1260 ! CALCULATION OF Qnet
1270 Qnet(J)=Power(J)-Qloss
1290 !
1300 ! CALCULATION OF Tfilm
1310 Tfilm(J)=(Tavg(J)+Tsink)/2
1330 !
1340 ! CALCULATION OF A DELTA TEMPERATURE
1350 Delt(J)=Tavg(J)-Tsink
1370 !
1380 ! CALCULATION OF CONVECTION COEFFICIENT
1390 H(J)=Qnet(J)/(Aatot*Delt(J))
1410 !
1420 ! CALCULATION OF FC-75 THERMAL CONDUCTIVITY.
1430 K(J)=(.65-7.89474E-4*Tfilm(J))/10
1440 !
1450 ! CALCULATION OF FC-75 DENSITY
1460 Rho(J)=(1.825-.00246*Tfilm(J))*1000
1470 !
1480 ! CALCULATION OF FC-75 SPECIFIC HEAT
1490 Cp(J)=(.241111+3.7037E-4*Tfilm(J))*4180
1500 !
1510 ! CALCULATION OF FC-75 VISCOSITY
1520 N(J)=1.4074-2.964E-2*Tfilm(J)+3.8018E-4*Tfilm(J)^2-2.7308E-5*Tfilm(J)^3+.
1529E-9*Tfilm(J)^4
1530 N(J)=N(J)+1.E-6
1540 !
1550 ! CALCULATION OF THE COEFFICIENT OF THERMAL
1551 ! EXPANSION (BETA)
1560 Beta(J)=.00246/(1.825-.00246*Tfilm(J))
1570 !
1580 ! CALCULATION OF ALPHA
1590 Alfa(J)=K(J)/(Rho(J)*Cp(J))
1600 !
1610 ! CALCULATION OF PRANDTL NUMBER.
1620 Pr(J)=N(J)/Alfa(J)
1630 !
1640 ! CALCULATION OF NUSSELT NUMBERS
1650 Nu1(J)=H(J)*L1/K(J)
1651 Nu2(J)=H(J)*L2/K(J)
1670 !
1710 ! CALCULATION OF GRASHOF NUMBER.
1720 Gr(J)=9.81*Beta(J)*(L1^3)*Delt(J)/N(J)^2
1740 !
1750 ! CALCULATION OF RAYLEIGH NUMBER.
1760 Ra(J)=Gr(J)*Pr(J)+1.E-7
1780 !
1794 ! CALCULATION OF FLUX BASED RAYLEIGH NUMBER
1810 Raf(J)=((9.81*Beta(J)*L1^4*Qnet(J))/(K(J)*N(J)*Alfa(J)*Aatot))+1.E-9
1830 !
1870 !*****
1880 PRINT USING "10X,D,1X,5(X,DD,DD,)";J,Qnet(J),Delt(J),Nu1(J),Nu2(J)
1890 !
1930 PRINT USING "12X,.""FLUX BASED RAYLEIGH NUMBER * E-9 IS: "" ,DDD,DD";Raf(J)
1940 PRINT USING "12X,.""AVERAGE TEMPERATURE:"",DDD,DD";Tavg(J)
1950 PRINT USING "12X,.""SINK TEMPERATURE:"",DDD,DD";Tsink

```

1960 NEXT J  
1970 ASSIGN #File TO ▶  
1980 END

```

1      !+++++*****
10     ! PROGRAM FASTSCAN *
11     !+++++*****
30     !PROGRAM TO SCAN THE THREE UPPERMOST THERMOCOUPLES.
40     ! IT SCANS 3 CHANNELS FOR TEMPERATURE VARIATION MEASUREMENTS.
41     ! CHANNELS ARE 13,31 AND 49
50     !+++++*****
60     !Pass=599
70     Pass=0
71     N=0
80     DIM T1(599),V1(2),Y1(599)
81     DIM T2(599),V2(2),Y2(599)
82     DIM T3(599),V3(2),Y3(599)
90     CLEAR 709
100    CLEAR 722
101    !+++++*****
102    ! THE THREE FILE NAMES THAT ARE REQUIRED FOLLOWING
103    ! ARE TO STORE THE READINGS FROM THREE THERMOCOUPLES.
104    !+++++*****
106    BEEP
107    PRINTER IS 701
108    BEEP
109    INPUT "ENTER THE FIRST FILE NAME: ".Newfile1$
110    INPUT "ENTER THE SECOND FILE NAME: ".Newfile2$
111    INPUT "ENTER THE THIRD FILE NAME: ".Newfile3$
112    INPUT "ENTER THE VOLTMETER READING: ".V$
113    PRINT USING "15X," RESULTS ARE STORED ON DISK 'FASTSCAN' "",10A"
114    PRINT
115    PRINT USING "25X,""FILE: "",10A";Newfile1$
116    PRINT
117    PRINT USING "25X,""FILE: "",10A";Newfile2$
118    PRINT
119    PRINT USING "25X,""FILE: "",10A";Newfile3$
120    PRINT
121    PRINT
123    WAIT 1
124    BEEP
125    OUTPUT 709:"AE!"
130    WAIT 2
131    BEEP
140    OUTPUT 722:"T4 F1 R1 P0 Z0 ISTI S01 ISTN"
141    !
143    !+++++*****
144    ! LOOP NUMBER ONE *
145    !+++++*****
146    ! START SCANNING CHANNEL # 13 *
147    !+++++*****
150    OUTPUT 709:"AF13 AL13"
160    OUTPUT 709:"AS"
170    BEEP
175    TImedate1=TIMEDATE
180    FOR J1=0 TO IPass
190    OUTPUT 722:"T3"
210    ENTER 722:V1(*)
220    T1(Pass)=V1(1)
250    Pass=Pass+1
251    N=N+1
260    NEXT J1
261    TImedate2=TIMEDATE
263    WDTBWTIme2:TImedate2-TImedate1

```



```

264 Pass=0
265 !*****
266 ! LOOP NUMBER TWO *
267 !
268 ! START SCANNING CHANNEL 31 *
269 !*****
270 !
271 OUTPUT 709:"AF31 AL31"
272 OUTPUT 709:"AS"
273 BEEP
274 BEEP
275 FOR JJ=0 TO Ipass
276 OUTPUT 722:"T3"
277 ENTER 722:V2(+ )
278 T2(Pass)=V2(I)
279 Pass=Pass+1
280 NEXT JJ
281 OUTPUT 722:"AC31"
282 Pass=0
283 !*****
284 ! LOOP NUMBER THREE *
285 !*****
286 ! START SCANNING CHANNEL 49 *
287 !*****
288 !
289 OUTPUT 709:"AF49 AL49"
290 OUTPUT 709:"AS"
291 BEEP
292 BEEP
293 BEEP
294 FOR JJ=0 TO Ipass
295 OUTPUT 722:"T3"
296 ENTER 722:V3(+ )
297 T3(Pass)=V3(I)
298 Pass=Pass+1
299 NEXT JJ
300 !
301 ! END LOOPS
302 !
303 PRINT USING "15X,""THE TOTAL TIME ELAPSED (XSECONDS)=";".2X,(DDD.DD)";total
time)
304 PRINT
305 PRINT USING "15X,""THE TOTAL NUMBER OF SCANS : ";".2X,(DDD.DD)";N
306 PRINT
307 PRINT USING "15X,""THE VOLTMETER READING : ";".10A,"";V
308 PRINT I; 1
309 DEC
310 !*****
311 ! TRANSFER FIRST SCAN DATA *
312 !*****
313 ! TRANSFERRING THE SCAN DATA FROM CHANNEL 31
314 ! TO THE FILE. THIS FILE WILL BE USED , WITH
315 ! THE PROGRAM "PLOT", TO MAKE A PLOT OF TEM-
316 ! PERATURE VS TIME.
317 !*****
318 CREATE Bdat Newfile15.20
319 ASSIGN #File TO Newfile15
320 OUTPUT #File:T1(+ )
321 FOR I1=0 TO Ipass
322 T1(I1)=.10086091+25727.9+T1(I1)-757345.8+T1(I1)^2+78002556+T1(I1)^3

```

```

340 NEXT I1
341 !+++++
342 ! TRANSFER SECOND SCAN DATA
343 !+++++
344 ! TRANSFERING DATA FROM CHANNEL 31
345 ! TO THE FILE
346 !+++++
347 CREATE BDAT Newfile2$.20
348 ASSIGN %File TO Newfile2$
349 OUTPUT %File:T2(+)
350 FOR I1=0 TO Ipass
351 T2(I1)=.10086091+25727.9*T2(I1)-767345.8*T2(I1)^2+78002556*T2(I1)^3
352 NEXT I1
353 !+++++
354 ! TRANSFER THIRD SCAN DATA
355 !+++++
356 ! TRANSFERING DATA FROM CHANNEL 31
357 ! TO THE FILE
358 !+++++
359 CREATE BDAT Newfile3$.20
360 ASSIGN %File TO Newfile3$
361 OUTPUT %File:T3(+)
362 FOR I1=0 TO Ipass
363 T3(I1)=.10086091+25727.9*T3(I1)-767345.8*T3(I1)^2+78002556*T3(I1)^3
364 NEXT I1
365 STOP
366 END

```

```

10 ! FILE NAME: PLOT
20 !
40 !
50 ! THIS PROGRAM PLOTS THE DATA ACQUIRED BY
60 ! PROGRAM "FASTSCAN".
70 !
80 PRINTER IS 705
90 BEEP
100 Xmin=0
110 Xmax=200
120 BEEP
130 INPUT "ENTER MINIMUM AND MAXIMUM Y-VALUES".Ymin,Ymax
140 BEEP
150 Xstep=.20
160 BEEP
170 Ystep=.2
180 BEEP
190 PRINT "IN:EP1:IP 2000.2000.8000.7000:"
200 PRINT "SC 0.100,0.100;TL 2.0;"
210 Sfx=100/(Xmax-Xmin)
220 Sfy=100/(Ymax-Ymin)
230 PRINT "PU 0.0 PD"
240 FOR Xa=Xmin TO Xmax STEP Xstep
250 X=(Xa-Xmin)*Sfx
260 PRINT "PA";X;".0; XT;"
270 NEXT Xa
280 PRINT "PA 100.0;PU;"
290 PRINT "PU PA 0.0 PD"
300 FOR Ya=Ymin TO Ymax STEP Ystep
310 Y=(Ya-Ymin)*Sfy
320 PRINT "PA 0.;Y;"YT"
330 NEXT Ya
340 PRINT "PA 0.100 TL 0.2"
350 FOR Xa=Xmin TO Xmax STEP Xstep
360 X=(Xa-Xmin)*Sfx
370 PRINT "PA";X;".100; XT"
380 NEXT Xa
390 PRINT "PA 100.100 PU PA 100.0 PD"
400 FOR Ya=Ymin TO Ymax STEP Ystep
410 Y=(Ya-Ymin)*Sfy
420 PRINT "PD PA 100.;Y;"YT"
430 NEXT Ya
440 PRINT "PA 100.100 PU"
450 PRINT "PA 0.-2 SR 1.5.2"
460 FOR Xa=Xmin TO Xmax STEP Xstep
470 X=(Xa-Xmin)*Sfx
480 PRINT "PA";X;".0;"
490 PRINT "CP -2.-1;LB";Xa;"
500 NEXT Xa
510 PRINT "PU PA 0.0"
520 FOR Ya=Ymin TO Ymax STEP Ystep
530 IF ABS(Ya)<1.E-5 THEN Ya=0
540 Y=(Ya-Ymin)*Sfy
550 PRINT "PA 0.;Y;"
560 PRINT "CP -5.-.25;LB";Ya;"
570 NEXT Ya
580 BEEP
590 Idl=0
600 IF Idl=0 THEN

```

```

520  Xlabel$="Time (sec)"
530  BEEP
540  Ylabel$="Temperature (C)"
550  PRINT "SR 1.5,2:PU PA 50,-10 CP";-LEN(Xlabel$)/2;"0:LB":Xlabel$:""
560  PRINT "PA -11,50 CP 0."; -LEN(Ylabel$)/2+5/6;"DI 0,1:LB":Ylabel$:""
570  END IF
580  PRINT "CP 0,0"
590  BEEP
700  INPUT "ENTER THE NAME OF THE DATA FILE".D_file$
710  ASSIGN %File TO D_file$
720  BEEP
730  Md=0
740  BEEP
750  Noairs=600
760  BEEP
770  PRINTER IS 1
780  Sym=1
790  PRINTER IS 705
800  PRINT "PU DI"
810  IF Sym=1 THEN PRINT "SM."
820  IF Sym=2 THEN PRINT "SM+"
830  IF Sym=3 THEN PRINT "SMo"
840  IF Md>1 THEN
850  FOR I=1 TO (Md-1)
860  ENTER %File:Xa,Ya
870  NEXT I
880  END IF
890  FOR Xa=0 TO 199 STEP .3333333
900  ENTER %File:Ya
910  Ya=.10086091+25727.9+Ya-767345.8+Ya^2+78002556+Ya^3
920  X=(Xa-Xmin1)*Sfx
930  Y=(Ya-Ymin1)*Sfy
940  IF Sym=3 THEN PRINT "SM"
950  IF Sym=4 THEN PRINT "SR 1,4,2,4"
960  PRINT "PA",X,Y,"PD"
970  IF Sym=3 THEN PRINT "SR 1,2,1,6"
980  IF Sym=4 THEN PRINT "UC2,4,99,0,-8,-4,0,0,9,4,0,:"
990  IF Sym=5 THEN PRINT "UC3,0,39,-3,-6,-3,6,3,6,3,-6,:"
1000 IF Sym=6 THEN PRINT "UC0,5,3,99,3,-8,-6,0,3,8,:"
1010 IF Sym=7 THEN PRINT "UC0,-5,3,99,-3,8,6,0,-3,-9,:"
1020 NEXT Xa
1021 PRINT "PU"
1030 BEEP
1040 ASSIGN %File TO *
1050 END

```

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protrusions in an en-  
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